GEOLOGY
AND
MINERAL RESOURCES OF ORISSA

SGAT
BHUBANESWAR

Society of Geoscientists
and Allied Technologists

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AND
MINERAL RESOURCES OF ORISSA

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Geology and Mineral Resources of Orissa

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PREFACE

The landmass constituting the State of Orissa covers an area of 155,707 sq. kms. The land has attracted the attention of several geoscientists, explorers and entrepreneurs for over a century on account of its diverse geological setting, rich and varied mineral treasures.

The first record of geological study in the State dates back to 1850s when mention was made about the coal resources in Talcher area in the Memoirs of the GSI by Dr. Thomas Oldham. During 1872, W.T. Blanford had authored a note entitled 'Sketch of Geology of Orissa', which is incorporated in the Records of the GSI, Vol 5 (Part - 2). During the 1870s, records of further studies in Talcher field were made by F. Fedden and there was a mention about occurrence of diamond in Hirakud by V. Ball in Records of GSI, Vol. 10 (Parts 2 & 4), 1877. Subsequent years and particularly the first decade of this century saw the coming into limelight the iron ore deposits at Gorumahisani and Badampahar by P.N. Bose. The monumental work by H.C. Jones during the early 1930s led to the delineation of almost all the major iron ore deposits in Keonjhar - Bonai region. The geology of Gangpur State (now a part of Sundargarh district) was studied by M.S. Krishnan during 1930s. The first attempt however to document the geology and mineral resources of Orissa was made in the publication entitled 'The Economic Geology of Orissa' by the officers of the GSI in 1949. Since then, the geology, structure and tectonics of the State have been studied in considerable detail by the Geological Survey of India. Following creation of the Directorate of Mining & Geology in the year 1955, the pace of mineral investigations was intensified and the investigation programmes were taken up in close co-ordination with the GSI and other Central Government agencies. Availability of satellite imageries around the later part of 1970s further facilitated geological mapping and delineating exploration targets. As a result of the pioneering efforts of the officers of GSI and the Directorate of Mining & Geology, a reasonably fair picture of the geology and mineral resource potential of the State is now available. The geological map of the entire landmass of the State has been completed in the scale of 1:50,000 by the GSI.

A rough breakup of the areas covered by the various rock types in the State as revealed from geological mapping carried out by the GSI is as follows :

Greenstones	24,100 sq.kms.
Gneisses etc.	52,000
Granitoids	12,000
Granulite	24,900
Gondwanas	12,400
Quaternary & Tertiary	30,300

The other organisations and institutions who have made significant contributions in the fields of geological research, exploration and proving of mineral deposits include. the Orissa Mining Corporation, Coal India Limited, Steel Authority of India Limited, Tata Steel, Mineral Exploration Corporation Limited, Indian Bureau of Mines, Department of Atomic Energy, Hindustan Zinc Limited, Oil India Limited, Presidency College, Calcutta; Utkal University among others. However, a comprehensive document about the geology, mineral resources of the State and the status of development was not available.

The Society therefore decided to compile a volume incorporating the latest information about the geology and mineral potential of the State. The task was quite stupendous and it required collection of information from various sources. I gratefully acknowledge the contributions made by the authors and the assistance rendered by the Directorate of Mining and Geology, Orissa Mining Corporation, GSI and host of other organisations and individuals in compiling the volume.

I am indebted to Dr. N.K. Mahalik, Professor in the Department of Geology, Utkal University and General Secretary of the Society and Dr. R.N. Mishra, Deputy Director General, GSI and Vice President of the Society for assisting me in editing the volume. The outcome of our modest efforts in the shape of the compiled volume 'Geology and Mineral Resources or Orissa', I am sure, will be useful to those who seek to know something about the geological setting of the State and its enormous mineral development potential. I am conscious of the possibility and need for further improvement and periodic updating of the contents in the volume.

B.K. Mohanty
President, SGAT

Bhubaneswar
15, April 1995

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Geomorphology

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1. INTRODUCTION

The State of Orissa is a part of the Eastern Ghat geomorphic province of India. Its geomorphology is characterised by a central axial highland flanked by low lying topographies and a coastal plain of varying width all along the eastern sea board. Mahanadi is the biggest river system which cuts across the central highland from west to east and forms an arcuate delta at its confluence with the Bay of Bengal.

The geomorphological features seen in the State can be grouped into two provinces; **highland province** and **coastal province**. The features in highland province are mostly of denudational nature while those in the coastal province are of depositional origin.

2. GEOMORPHOLOGY OF THE HIGHLAND PROVINCE

Linearly disposed hill ranges, intervening valleys, plateaus, uplands and peneplains occupying different heights and formed over different bedrocks characterise the highland province. They could be discussed under two subgroups:features above 500 m and features within 500 m above mean sea level (aMSL). The former usually are found over the central axial zone wile the latter flanks on either side of the central axial zone.

2.1 Features above 500m aMSL

2.1.1 Plateau

Several plateaus are observable in the central axial highland areas. These are more or less flat surfaces with abrupt descent at the margins. The most important plateau surfaces are given in table 1. Most of these plateau surfaces carry a duricrust, either bauxite or laterite. However the Jeypore plateau which is formed over granitic rocks does not carry any duricrust.

Table 1. Plateaus in Orissa

Name of Plateau	Country rocks	Typical features
Simlipal plateau (Mayurbhanj district)	Volcanics and metasedimentary rocks of SIMLIPAL Group.	Located 700-800m aMSL, dissected nature, carries laterite duricrust. Surrounding country 300-400 m aMSL.
Keonjhar plateau (Keonjhar district)	-do-	Located 700-800 m aMSL; carries bauxite duricrust.
Gandhamardan plateau (Bolangir-Sambalpur district)	Khondalite rocks of Eastern Ghats Group	900-1,000 m aMSL. Carries bauxite duricrust.
Baphlimali plateau (Kalahandi district.)	-do-	Over 1200 m aMSL, carries bauxite duricrust
Panchpatmali plateau, Koraput district.	-do-	-do-
Koraput plateau (Koraput district.)	Khondalite and charnockite.	Over 900 m aMSL; dissected, carries laterite duricrust.
Nuapara plateau (Kalahandi district.)	Chhatishgarh group of sedimentary rocks.	600-900 m aMSL, laterite and minor bauxite duricrust exist.
Jeypore plateau (Koraput district)	Granites and gneisses.	500-600 m aMSL. No duricrust is observed.

2.1.2 Linear hill ranges and valleys

There are numerous linear hill ranges and valleys conforming to the strike trends of many rock groups, The ridges are formed in competent rocks while the valleys are formed in the weaker rock formations. The important hill and valley geomorphologies are discussed as under.

a) Horse shoe syncline hill ranges and valleys: (Barsua-Koira-Joda area)

The banded iron formation (BIF) of this area show NNE-SSW trending structural hills and valleys. The resistant banded hematite quartzites make fairly continuous ridges on either side of a central valley (Koira valley). The latter has formed on the weaker shales. The closure of the syncline is marked by high hills e.g. Chhelia toka (1015m), Baliapahar (1010m), Khandadhar pahar (877 m) and Mankarnacha (1117 m). Most of the hill ranges carry iron ore while the valley areas are associated with manganese ore.

b) Deogarh hill range

This is a prominent hill range running east - west around Deogarh in Sambalpur district. The hills are formed of resistant quartzites containing horizons of BIF. They show prominent fold closures.

c) Riamal -Kamakhyanagar hill ranges

A series of parallel east - west hill ranges intervened with valleys run between Riamal (73 C/11) on the west and Kamakhyanagar (73 H/9) on the east.

d) Malyagiri-Kamakhyanagar structural hills

A prominent hill range runs between Malyagiri on the northwest and Kamakhyanagar in southeast. These are formed in medium grade metamorphosed BIF rocks.

e) Gangpur structural hills and valleys

The Gangpur hills and valleys are well developed on the Gangpur and Darjing group of rocks maintaining the ENE-WSW structural trends of rocks.

2.2 Features within 500m aMSL

The important geomorphic features are the upland topographies, peneplains and linear depressions.

2.2.1 Upland topography

It is an intermediate level erosional surface without steep slopes at its margin. Peneplanation is usually not complete. Some of the important uplands are developed in Baitarani, Brahmani, Ib, Tel, Rushikulya drainage basins.

a) Baitarani upland

This is a very significant upland in north Orissa developed over Singhbhum Granites . It is a low-lying erosional surface in between Simlipal plateau in the east and Keonjhar plateau in the west. The level difference between Baitarani upland and the neighbouring highland is as much as 200 to 450 m. This terrain shows an interlacing network of dolerite dykes which stand out as low linear ridges running over long distances. The general height of this upland varies between 300-400 aMSL.

b) Brahmani -Ib upland

Brahmani - Ib upland is situated in the northwestern sector of Orissa and is formed over granites and granitic gneisses. It ranges in height between 100-450 m aMSL. The Ib upland is more even while the Brahmani upland contains many isolated structural ridges.

c) Tel upland

It has been developed over unclassified granites and gneisses in Tel basin. The relief varies from 150m to 300m aMSL

d) Rushikulya upland

This is highly uneven with numerous isolated hillocks distributed irregularly. The relief varies between 75 to 300m aMSL. The geologic base is made up of khondalite, charnockite and migmatitic gneisses.

e) Gondwana upland

The area is characterised by low lying erosional surface merging with the lateritic peneplains. The height ranges between 150 to 300m above mean sea level.

2.2.2 Peneplains

These are very low lying flat lands representing the final stage of mass wasting. They are made up of either laterites or black soil.

a) Lateritised Peneplains

The lateritic peneplains are low level extensively flat laterite bearing areas developed over a variety of country rocks e.g. khondalites (Khurda area), Gondwana rocks (Bhubaneswar area) ultrabasic rocks (Sukinda area) etc. They are usually found fringing the western margin of the deltaic plains. The ground elevations range from 20 m to 75 m aMSL.

b) Non-lateritised peneplains

In contrast to the lateritised peneplains non - lateritised peneplains have been developed in many places covered by light to dark grey coloured residual soils. The country rocks are usually a variety of gneisses, migmatites and charnockitic rocks. Black soil covered flat areas are typically seen over anorthosites of Bolangir area. Extensive peneplains are seen around Aska, Hindol, Angul, Boud, Sukinda, Bhubaneswar etc.

2.2.3 Linear Depressions

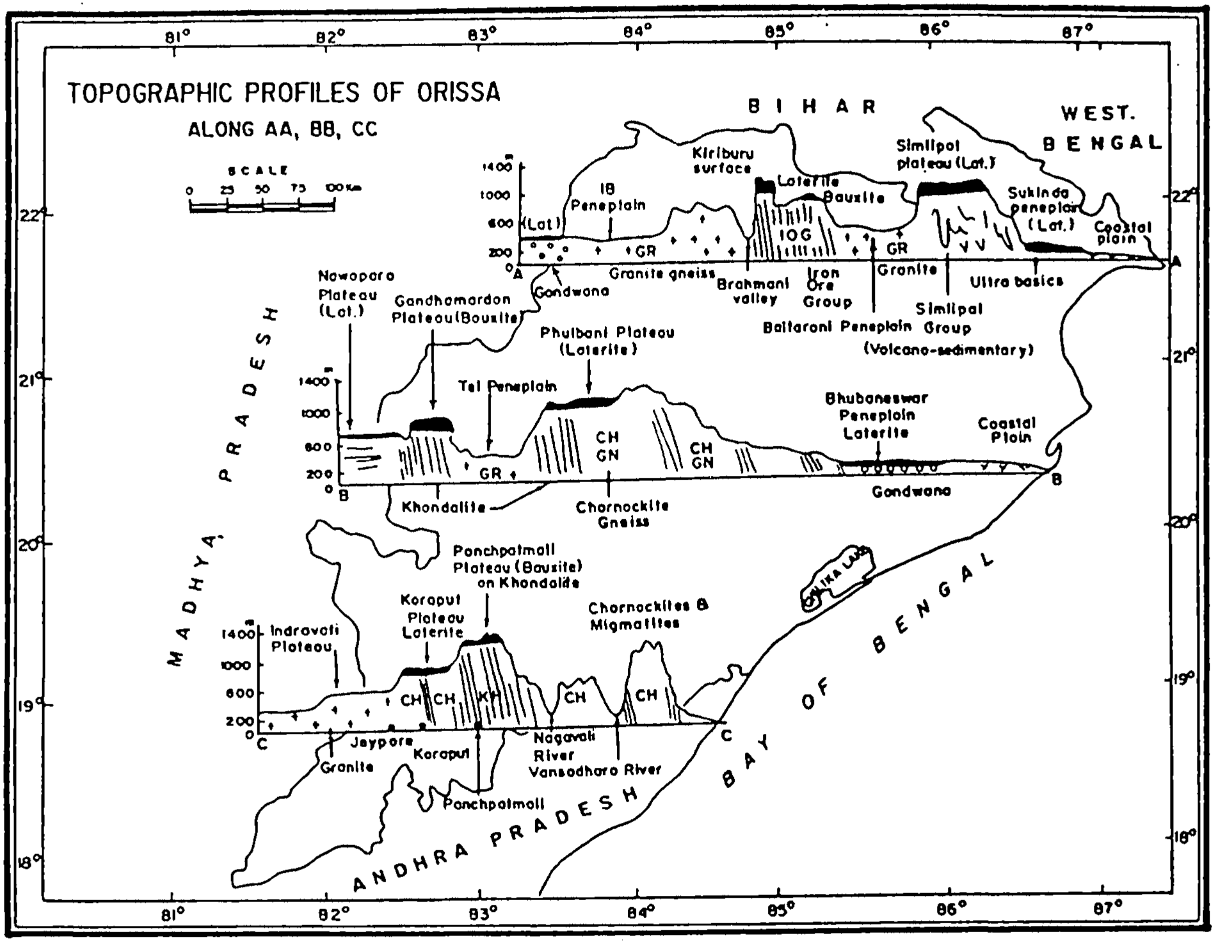
Narrow linear depressions or valleys are seen between high ridges. Typical examples are Tikerpara gorge, Nagavalli and Vanshadhara depressions. They probably represent shear/fault zones.

2.3 Planation (erosional) surfaces in Highland Topography

Multilevel planation surfaces are typical in the highland province of Orissa (Mahalik, 1994). They are evenly flat or undulating and are covered by variable end products of weathering e.g. bauxite, gibbsite bearing laterite, ordinary laterites, black soil, dark grey to light coloured residual soils. They represent long continued weathering under tectonic stability. Planation surfaces at different levels indicate differential erosion on varying rock formations and possibly mild vertical movements. The higher planation surfaces carry bauxite and are considered oldest surfaces whereas the lowest planation surfaces carry non-bauxitic laterites and are considered as youngest. Table 2 shows the various planation surfaces and their characteristic features. Figure enclosed shows the different planation surfaces along three topographic profiles of Orissa.

Table 2. Planation Surfaces in Highland Province.

Height aMSL	**Geomorphology**	**Country rock.**	**Nature of residuum**	**Location & other remarks**	**Possible age**
600-1500 m	Plateau	Khondalite, Charnockite, Basic igneous rocks, BIF, Proterozoic sedimentaries	Bauxite, gibbsitic laterite.	Panchpatmali Gandhamardan Kuanr, Simlipal, Kiriburu, Nuapada plateau	Eocene
150-600 m	Upland upland-peneplain	Granites & gneisses.	Rare duricrust,	Baitarani, Ib, Tel and Indravati uplands	Oligocene
20-150 m	Peneplain	Khondalite	Nonbauxitic laterite.	Khurda	
		Ultrabsic rocks.	-do-	Sukinda	Post Mio-Pliocene to Recent
		Gondwana rocks.	-do-	Bhubaneswar	
		Anorthosite	Black soil (very typical)	Bolangir Chilika area	
		Gneisses	Dark soil	Aska.	



TOPOGRAPHIC PROFILES OF ORISSA
ALONG AA, BB, CC

3. GEOMORPHOLOGY OF COASTAL PROVINCE

A long coastal plain of varying width is seen all along the eastern sea board of Orissa. A maximum width of 50 km is seen in Mahanadi delta. The various geomorphic features constituing the coastal plain are formed by deposition of sediments under fluvial, sea marginal, marine and aeolian environments. The various features observed are : wide extensive alluvial flood plains, natural levees, paleo channels, beaches, beach ridges, tidal flats, mangrove swamps, spits, bars, bays and lakes. Chilika is a prominent lake and has been formed by embayment of the sea by formation of spits and bars. Jatadhar Muhan and Hukitola bay are similar features along the coast.

4. RIVER SYSTEM

Rivers constitute major geomorphic features of any region. Orissa has numerous rivers and from north to south they are Subarnarekha, Budhabalang, Baitarani, Brahmani, Mahanadi -Tel, Rushikulya, Vansadhara, Nagavalli, Machhkund-Balimela - Sileru, Kolab-Sabari and Indravati. All of them directly or indirectly join the Bay of Bengal at different outfalls. The last three form part of the Godavari River system. Some of the rivers are of local origin e.g. Budhabalang, Baitarani, Rushikulya, Nagavalli, Vansadhara etc. Mahanadi is the biggest river system with a large drainage basin stretching into Madhya Pradesh and Bihar. It forms a major delta at its confluence with the Bay of Bengal. The next biggest is the Brahmani river with its drainage basin stretching into Bihar State.

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Structure and Tectonics

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1. INTRODUCTION

The geological history of Orissa has been associated with many tectonic events resulting in important structural features such as fold systems, faults, lineaments, grabens, circular patterns and tectonic trends. No attempt has been made to study them in any detail. The Map enclosed gives some of the important features observed mostly from study of satellite images. They are discussed here under different categories.

2. STRUCTURAL FEATURES

2.1. Circular features : Four circular features are observable in the satellite images. They are : (1) Phulbani feature, (2) Simlipal feature, (3) Gandhamardan feature and (4) Kunjar feature. All four of them occupy highland areas forming plateau surfaces. Features 2,3 and 4 are covered by sedimentary basins while feature 1 is in Phulbani charnockitic terrain.

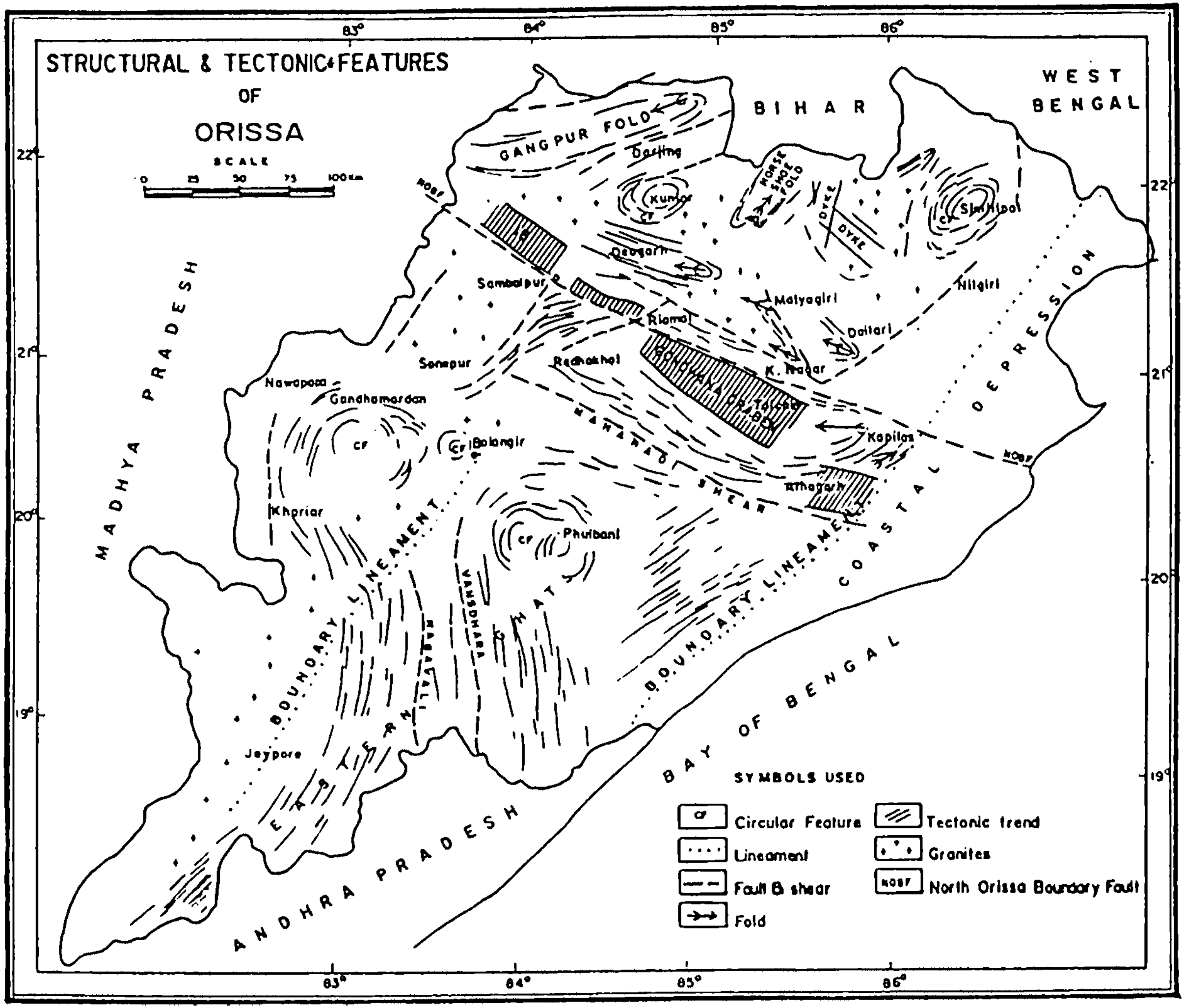
Phulbani feature : It consists of circular domes of granulites and charnockites (Nash & Leeming, 1993), rimmed by khondalites on the west with a fault contact (Tumudibandh fault).

Simlipal feature : It is a circular sedimentary basin over the Singhbhum granite body. Very likely the basin was formed on a circular pluton of Singhbhum Granite family.

Gandhmardan feature : This circular feature is rimmed by the khondalites of the Eastern Ghats. Most probably it is a pluton intrusive into the Eastern Ghat supracrustals.

Kunjar feature : It lies in Sundargarh district northwest of Bonai granite and is covered by rocks of Kolhan age (?). The shape is most likely due to an igneous intrusive beneath the supracrustals.

The tectonic aspects of these circular features have not been studied by any earlier workers.



STRUCTURAL & TECTONIC FEATURES OF ORISSA

2.2. Lineament Features : Two very important lineaments have been delineated which shape the NE-SW trending Eastern Ghats. The western boundary of the Eastern Ghats is a significant lineament which runs between Bolangir and Jeypore and is characterised by both topographic and gravity differences on either side. The eastern boundary of the Eastern Ghats is also believed to be a fault related lineament responsible for the formation of coastal depression.

2.3. Faults & Shear Zones : Many significant faults and shear zones have been delineated in Orissa. The prominent fault is the North Orissa Boundary Fault (Mahalik 1984, 1994) running from the western border to the eastern coast of the State. The central part of this fault was recognised earlier by Prasad Rao et al (1964) as "Sukinda Thrust". Mahalik (1984) extended it to east and west for a much longer distance and termed it as North Orissa Boundary Fault (NOBF). It forms the boundary between the north Orissa craton on the north and Eastern Ghats Mobile Belt to south. Detailed work along this fault has delineated as many as four parallel faults. The Gondwana graben is associated with these set of faults.

The western extension of the "Singhbhum Thrust" is seen on the northwestern corner of the State in Sundargarh district, while its eastern extension veers into Orissa, east of Simlipal plateau. The southern boundaries of Gangpur Group and Darjing Group appear to be sheared and faulted which are genetically related to the Singhbhum thrust. Other minor faults are seen between Kamakhyanagar-Nilgiri, Riamal-Redhakhol, Sambalpur-Sonepur, Nuapada-Khariar and Malyagiri - Kamakhyanagar.

Three shear zones are identified: Nagavali and Vansadhara rivers are flowing through two distinct shear zones with NW-SE trends. These are characterised by two deep depressions between high hill ranges. From Sonepur to Naraj, Mahanadi river is flowing along a possible shear zone.

2.4 Folded units : Major fold sequences are seen at several places; (i) the horse shoe synclinorium : This is a well known folded sequence affecting the Iron Ore Group rocks around Koida-Joda area of North Orissa. It is NNE plunging and its western limb is overturned. (ii) The Gangpur Group on the northwest is folded into a synclinorium with both of its limbs overturned (Kanungo & Mahalik, 1975). It has a ENE-WSW trend with variable plunge to ENE or WSW. (iii) Kapilas fold : A major fold closure (synformal) in the khondalites of Eastern Ghats is well seen at Kapilas hill in Dhenkanal district. It has a south - westerly plunge. The northern limb of this fold is abruptly truncated by the North Orissa Boundary fault. Fold closures are also seen in Malyagiri, Daitari and Deogarh assemblages of iron ore bearing rocks.

2.5. Structural trends

Several well developed structural trends are seen in the different major rock groups of Orissa. Three typical structural trends are observable in the rocks of Eastern Ghats. These are the NE-SW trend, supposed to be the oldest; NW-SE trend, parallel to Nagavali & Vansadhara rivers, which affects the NE-SW trend and the E-W trend known as "Mahanadi trend" is believed to be the youngest. In North Orissa craton, several important tectonic trends can be distinguished; such as

Malyagiri trend :	NW-SE. It runs between Malyagiri and Kamakhyanagar
Deogarh trend :	E-W - exhibited by the east west running hill ranges
Horse-shoe trend:	NNE-SSW associated with the Horse-shoe syncline
Gangpur trend :	ENE-WSW associated with the Gangpur synclinorium

Each of the above trends is associated with major fold movements. Some of the older tectonic features such as Older Metamorphics, Older Metamorphic Tonalite Gneiss of Saha et al (1988) are not well reflected as mappable features.

2.6 Gondwana Graben

The grabenic units hosting the coal resources of Orissa are located within the central fault affected boundary between North Orissa craton and the Eastern Ghats Mobile Belt. They occur in three detached units at the Ib Valley, Brahmani Valley and Mahanadi Delta head. A narrow connection exists between the first and second units.

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Precambrians

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1. INTRODUCTION

The Precambrians of Orissa embrace a vast time span from about 4000 My to 600 My and occupy about 80% of the land surface of the State. They are also the store house of most of the economic mineral deposits e.g. iron ore, manganese ore, chromite, nickel ore, cobalt, bauxite, copper, lead, zinc, tin, limestone, dolomite, graphite, gemstones, dimension stones etc.

The Precambrians are very complex lithologically, genetically, tectonothermally and differ in their ages of formation. They could be broadly divided into the Archaean and the Proterozoic.

Extensive literature exists on these rocks which is difficult to cite here. The present description tries to take into account some of the writings of the recent times.

Following Naqvi and Rogers (1987) the Orissa Precambrians are segmented into three geologically significant sectors as shown in Fig. 1. The geology of the Precambrians in these sectors typically differs from each other. The three sectors are : **North Orissa sector** comprising parts of the Singhbhum-North Orissa craton with banded iron formation greenstone - granite association, **South Orissa sector** comprising the Eastern Ghats Mobile Belt with high grade granulite facies rocks and the **West Orissa sector** making the eastern margin of the Bhandara craton with a complex combination of greenstone, granite, granulite facies rocks and Purana (Proterozic) sedimentaries.

The contact of North Orissa sector (Sector-I) and South Orissa sector (Sector-II) is characterised by a series of east -west running faults (Mahalik, 1994) along which the Gondwana graben (Mahanadi graben) has formed. Along their eastern margins, both the sectors meet the coastal depression along a geomorphologically significant lineament. The western margin of the Eastern Ghats Belt (Sector-II) is also a geomorphologically significant lineament along which the eastern margin of the Bhandara craton (Sector-III) meets. The geology of the Precambrians has been dealt with reference to these three sectors. Fig 2 shows the geological map of Orissa based on satellite imageries and field study.

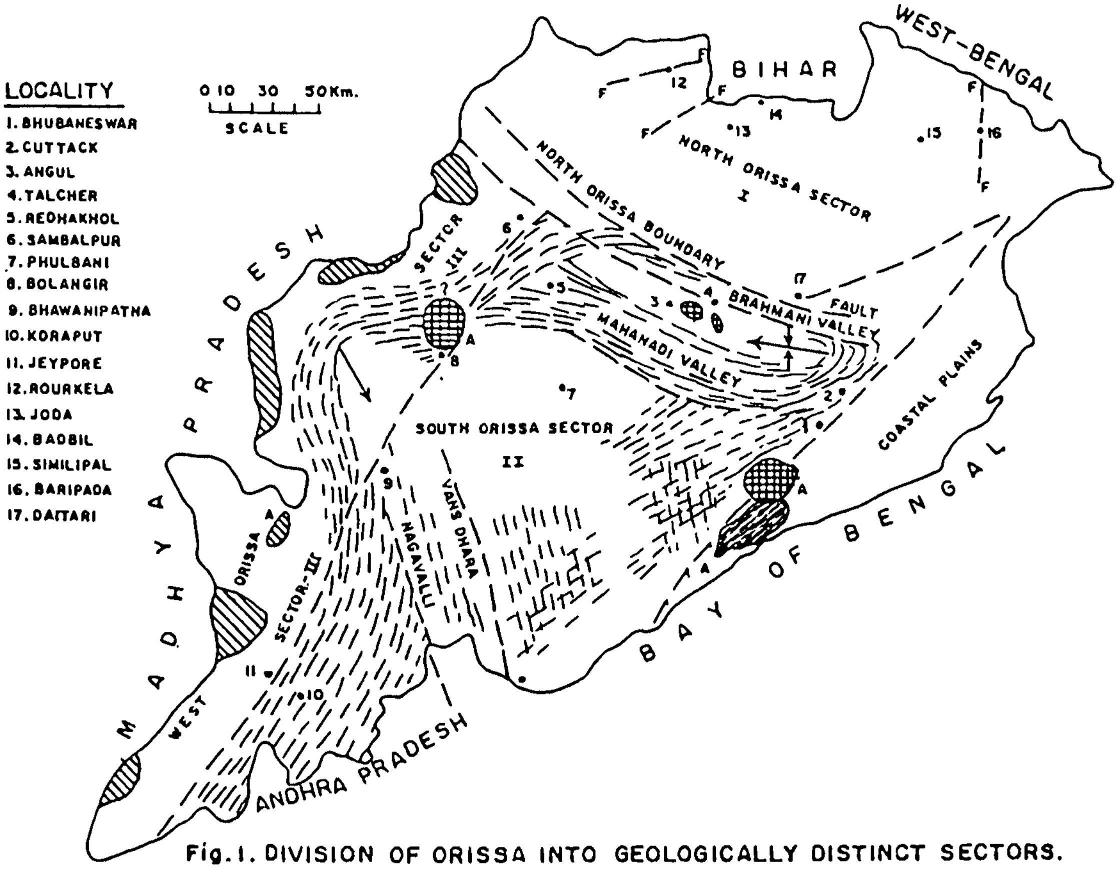

Fig. 1. DIVISION OF ORISSA INTO GEOLOGICALLY DISTINCT SECTORS.

2. DESCRIPTION OF PRECAMBRIANS

2.1 North Orissa (Sector I)

The rocks of North Orissa and adjoining Southern Singhbhum of Bihar State constitute a significant cratonic block with a rhombic shape and east-west elongation (Mahalik 1986). It is bounded by major faults (thrusts) along its peripheries e.g. the Singhbhum thrust on the north-west, north and north-east, the North Orissa boundary fault (Mahalik 1984 & 1994) on the south and the Kamakhyanagar -Nilgiri fault on the south-east.

Owing to the rich mineral potential of North Orissa, a number of geologists have worked in this region over the last hundred years or more and have given a wealth of information on its geology. The important works are by Acharya (1976, 1984), Banerjee, A.K. (1974, 1975, 1980), Banerjee, P.K. (1968), Basu et. al (1981), Dunn (1940), Dunn & Dey (1942), Iyengar & Anand Alwar (1965), Iyengar & Banerjee (1971), Iyengar & Murthy (1980), Jones (1934), Kanungo & Mahalik (1967, 1972, 1975), Krishnan (1937), Mahalik (1984, 1986, 1987, 1994), Majumdar (1978), Mukhopadhyay (1976, 1988), Murthy & Acharya (1975), Narayanswami (1975), Prasad Rao et.al (1964 a,b), Saha, Ray & Sarkar (1988), Sarkar & Saha (1962, 1977, 1983) etc.

A comprehensive review of literature shows that the North Orissa-Singhbhum craton consists of several major lithologic groups of sedimentary and igneous origin ranging in age from the oldest Archaean (4000My-3800My) to the younger Proterozic. The most important aspects of the craton is its association with several low grade metamorphics and Banded Iron Formation (BIF) as seen at Gorumahisani, Dubri, Daitari, Malyagiri, Deogarh, Barsua, Joda etc., interwoven with several major granitic intrusives e.g. Singhbhum granite, Bonai granite, Nilgiri granite, Mayurbhanj granite etc. Several volcano-sedimentary sequences (as at Similipal plateau, Keonjhar plateau) are also observed in close association with the Banded Iron Formation. The sedimentary history in North Orissa virtually closed with the deposition of iron free sediments both in geosynclinal (Darjing-Gangpur Group) and platformal environments (Kolhan Group).

There is considerable variation in opinion among the different workers regarding the number of BIF and the intrusive phase of Singhbhum granite complex. However, the following broad conclusions can be arrived at.

(1) According to Jones (1934), Dunn (1940), Dunn & Dey (1942), Sarkar and Saha (1962, 1977, 1983) all the BIF are classed into one group

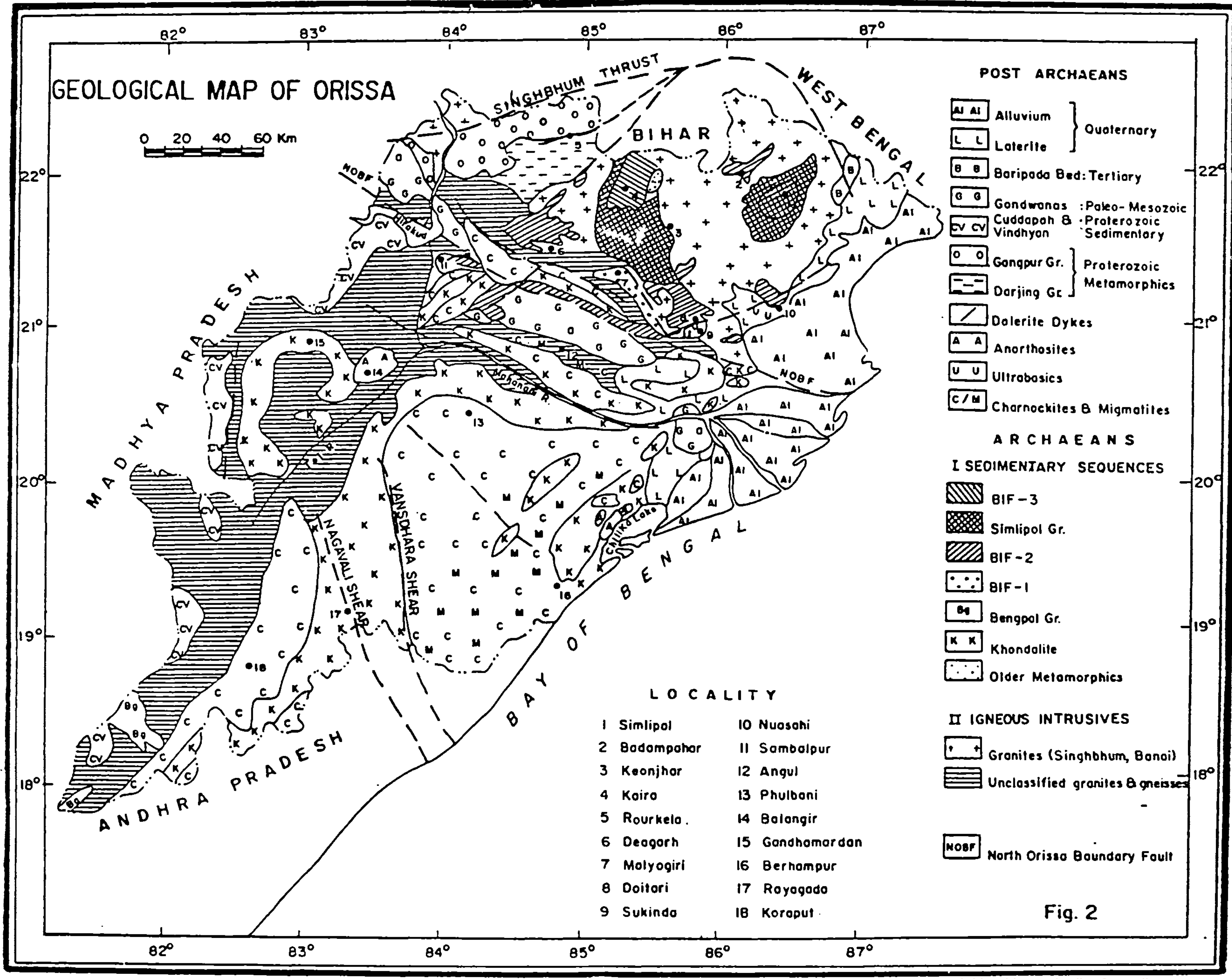
GEOLOGICAL MAP OF ORISSA
0 20 40 60 Km
82° 83° 84° 85° 86° 87°
22° 21° 20° 19° 18°
SINGHBHUM THRUST
BIHAR
WEST BENGAL
MADHYA PRADESH
ANDHRA PRADESH
BAY OF BENGAL
NOBF
Mahanadi R.
Chilka Lake
NAGAVALI SHEAR
VANSDHARA SHEAR
POST ARCHAEANS
Alluvium
Laterite
Quaternary
Baripada Bed: Tertiary
Gondwanas : Paleo-Mesozoic
Cuddapah & Vindhyan · Proterozoic Sedimentary
Gangpur Gr.
Darjing Gr.
Proterozoic Metamorphics
Dolerite Dykes
Anorthosites
Ultrabasics
Charnockites & Migmatites
ARCHAEANS
I SEDIMENTARY SEQUENCES
BIF-3
Simlipal Gr.
BIF-2
BIF-1
Bengpal Gr.
Khondalite
Older Metamorphics
II IGNEOUS INTRUSIVES
Granites (Singhbhum, Banai)
Unclassified granites & gneisses
NOBF North Orissa Boundary Fault
LOCALITY
1 Simlipal
2 Badampahar
3 Keonjhar
4 Kairo
5 Rourkela
6 Deogarh
7 Malyogiri
8 Daitari
9 Sukinda
10 Nuasahi
11 Sambalpur
12 Angul
13 Phulbani
14 Balangir
15 Gandhamardan
16 Berhampur
17 Rayagada
18 Koraput

Fig. 2

and these rocks are intruded by Singhbhum Granite. Some of them have recognised a basement with rocks classified as the Older Metamorphic Group. Saha and his associates have brought continuous modification to their ideas on the stratigraphic succession of this region since 1962. Their most recent idea (Saha et.al, 1988) is presented in more detail later.

(2) The second view is put forth by A.K. Banerjee (1974, 1975, 1980), Iyengar & Banerjee (1971), and Iyengar and Murthy (1980). According to them the BIF is classified into two groups, an older BIF (Gorumahisani) and an younger BIF (the horse-shoe syncline around Barsua, Joda, Noamundi etc.). They differ as to the number of intrusives forming the Singhbhum granite complex and its relation to the BIF and the volcano-sedimentary rocks of the region.

(3) Yet there is a third view presented by Prasad Rao et al (1964 a,b) and Acharya (1976, 1984). They are of the view that there are atleast three Iron Formations e.g., the oldest at Pallahara, Nausahi and Gorumahisani, the next younger at Daitari and Tomka and the youngest in Koira-Joda area. They differ in their views about the number and sequence of granite intrusives and their relation to the metasedimentary rocks of the region.

The volcano - sedimentary sequence as seen in Simlipal and Keonjhar plateaus and considered equivalent of the Dhanjoris are believed to be younger than the BIF by Saha and his associates while they are believed as sandwiched between BIF I and BIF II (Banerjee 1974, 1975, 1980, Iyengar & Banerjee 1971), and between BIF II and BIF III by Prasad Rao et al (1964 a,b) and Acharya (1976, 1984).

Saha and his associates have spent a considerable part of their research efforts in understanding and unravelling the geology of Singhbhum - North Orissa craton. They have stressed of the very ancient history of the craton as recorded in the rocks designated as the Older Metamorphic Group (4.0 Ga) and Older Metamorphic Tonalite Gneiss (3.775 Ga) followed upwards by Singhbhum Granite Phase A (C.3.3 Ga), Iron ore Group and Singhbhum Granite Phase B (C. 3.1. Ga). According to them all the BIF formations were formed in between 3.3 Ga and 3.1 Ga. All these Archaean events were followed by Proterozoic events such as Singhbhum Group. Dhanjori and Kolhans etc. The recent most generalised chronostratigraphic succession of rocks as suggested by Saha et al (1988) is given in Table-1.

Table-1

Generalised Chronostratigraphic Succession of Rocks in Singhbhum-North Orissa Craton (Saha, Ray & Sarkar, 1988).

Newer Dolerite dykes and sills	C. 1600-950 Ma
Mayurbhanj Granite	C. 2100 Ma
Gabbro, Anorthosite and Ultramafics	C. 2100-2200 Ma
Kolhan Group	
——— Unconformity ———	
Jagannathpur lavas, Dhanjori - Simlipal lavas Malangtoli lavas	Dhanjori Group
Quartzites and conglomerates	C. 2300 Ma
Pelitic and arenaceous metasediments with mafic sills	Singhbhum Group (C. 2300-2400 Ma)
——— Unconformity ———	
Singhbhum Granite Phase B. (Main phase of Bonai Granite)	C. 3100 Ma
Mafic lava, tuff, acid volcanics, tuffaceous shale, banded hematite jasper and banded hematite quartzite with iron ore, ferr. cherts, orthoquartzites, sericitic quartzite, conglomerate.	Iron Ore Group
Singhbhum Granite Phase A (main phase of Nilgiri granite)	C. 3300 Ma
Pallahara-Kamakhyanagar Granite gneiss Folding and metamorphism of Older Metamorphic Group and Older Metamorphic Tonalite Gneiss.	C. 3400-3500 Ma
Older Metamorphic Tonalit Gneiss (OMTG)	C. 3775 Ma
Older Metamorphic Group (OMG) with pelitic schists, quartzite, para and orthoamphibolite	C. 4000 Ma

2.11 Important Lithologic Groups

Archaean Rocks

All the major rocks related to BIF - Greenstone - Granite association are brought under Iron Ore Super Group. The major part of north Orissa is covered by the Singhbhum Granite batholithic complex which occupies a north-south elongated tract of about 8000 Sq. kms. Relicts of older formations such as the Older Metamorphic Group and Older Metamorphic Tonalite Group are found within the granitic batholith. The low grade metamorphics and Banded Iron Formation (BIF) surround the batholith along its north-west (Joda-Koira region), west (Deogarh region), south-west (Pallahara & Daitari region), south-east (Boula-Notopahar region) and north-east (Badampahar-Gorumahisani region). Important volcano-sedimentaries (Simlipal plateau and Keonjhar plateau) and ultrabasics (Sukinda valley) occur within some of the Banded Iron Formations. Some of the rock formations included within Iron Ore Super Group may belong to Proterozoic period.

Older Metamorphic Group (OMG) and Older Metamorphic Tonalite Gneiss Group

The OMG rocks occupy an area of about 200 Sq. kms. to the west of Champua (22°04' : 85°40') caught within the Singhbhum granitic batholith. They consist of medium grade pelitic schists, arenites, calc-schist, para and ortho-amphibolites. They are intruded and partly granitised by an extensive suite of biotite tonalite gneiss grading to trondhjemite which occupies a 900 Sq. kms. tract in the west central part of the batholithic complex. This is often referred to as Older Metamorphic Tonalite Gneiss (OMTG). According to Saha, Ray and Sarkar (1988), the OMG group of rocks are the oldest rocks in India with an age of around C 3.8 Ga. During C 3.8 to 3.7 Ga, the OMG was believed to have been folded and intruded by the OMTG.

Singhbhum Granite

The Singhbhum Granite Batholithic Complex occupies a north - south elongated tract of about 8000 Sq. kms. and is made up of atleast 12 magmatic bodies of biotite-granodiorite - granite emplaced in three distinct but closely related phases, phases I and II being C 3.3 Ga while Phase III members were emplaced around 3.1 Ga ago. The Phase I rocks are relatively potash poor granodiorite trondhjemite while the rocks of Phase II & III are granodiorites grading to adamellitic granite. Saha, Ray and Sarkar (1988) believe that the magma for Phase I & II Singhbhum granites were derived by partial melting of freshly accreted amphibolite at the base of the crust about C 3.3 Ga ago while the magma for Phase III granites was derived by partial melting of crustal rocks, probably a siliceous garnet-granulite about 3.1 Ga ago. There are three other smaller granitic intrusives in the area, viz., Bonai granite on the west , Nilgiri granite in the east and Mayurbhanj granite in the east-north-east. Bonai granite and Nilgiri granite indicate close resemblance with the different phases of Singhbhum granite, mainly

Phases I & II. Some of china clay deposits in north Orissa were formed by the weathering of Singhbhum granites.

Banded Iron Formation (BIF)

The Banded Iron Formation (BIF) more or less encircle the Singhbhum Granite batholith. Important BIF occurrences are located at Gorumahisani (north east), Daitari (south), Malyagiri (south-west), Deogarh (west) and Joda-Noamundi (north-west). Of these, the Joda-Noamundi, Daitari and Gorumahisani occurrences are rich in iron ore where active mining has been continuing since long.

The north western exposure between Barsua and Noamundi has been folded into the famous 'horse shoe' synclinorium (Jones, 1934). The BIF exposure at Daitari is intruded by ultrabasic rocks which hosts the chromite and nickel deposits of Sukinda Valley. All the Banded Iron Formation have undergone green schist facies metamorphism except in Kamakhyanagar-Malyagiri sector. Two distinct BIF sequences are seen between Kamakhyanagar and Malyagiri, an older sequence consisting of kyanite - staurolite grade schists and a younger sequence of low grade micaceous quartzites and banded magnetite quartzites, unconformably sitting over the older sequence. The younger Malyagiri sequence is equivalent of the Deogarh BIF.

Volcano - sedimentary association of Simlipal and Keonjhar Plateau

Included within the Iron Ore Super Group are the massive volcano-sedimentary assemblages forming Simlipal and Keonjhar plateaus. In Simlipal, they consist of an alternating sequence of spilitic lava and quartzites lying unconformably above the Singhbhum Granite and intruded by pyroxene granite, granophyre, gabbro and anorthosites (Iyengar and Anand Alwar, 1965). The rocks of Keonjhar plateau consists of extensive basic lavas and quartzites. The two assemblages are believed to be equivalent of the Dhanjori Group. Bauxite is found at Kuanr in Keonjhar plateau by weathering of basic volcanic rocks. It may be noted that extensive basic volcanic rocks are also associated with BIF occurrences of Deogarh Group. In the Deogarh sequence, these volcanics are older than the banded hematite quartzite member.

Proterozoic Rocks

In contrast to the BIF bearing greenstone sequence which evolved mostly during Archaean times there are other important metasedimentary assemblages which formed much later in Proterozoic basins. They do not contain any iron formation but detrital fragments of banded hematite rocks and granites are observed in them indicating their younger age. The important litho-groups are the rocks of Darjing Group, Gangpur Group and the Kolhan Group. The well known Gangpur Group of rocks, occurring in parts of Sundargarh district, were first studied by Krishnan (1937) who believed them to form an anticlinorium underlying the surrounding Iron Ore Group of rocks. They consist of a sequence of arenaceous, calcareous, carbonaceous and argillaceous rocks. The calcareous horizons contain rich deposits of limestone and dolomite. The argillaceous horizons show metamorphism upto staurolite grade. Later workers on Gangpur Group viz, Banerjee (1968) Kanungo & Mahalik (1967, 1972, 1975) established that the Gangpurs were younger than the Iron Ore Group. According to Kanungo & Mahalik (1967, 1975) the Gangpur were deformed into a synclinorium in total contradiction to the anticlinorium structure suggested by Krishnan (1937). Hence, the stratigraphic sequence of the rock units had to be but reversed. The revised stratigraphic sequence after Kanungo & Mahalik (1967) is presented in Table : 2.

Table-2

Stratigraphic Succession of Gangpur Group.

(After Kanungo & Mahalik (1967, 1975).

Goriajhor Formation	Staurolite and garnet schists, calc schists, manganiferous metasediments.
Kumarmunda Formation	Banded carbonaceous quartzites and phyllites.
Birmitrapur Formation	Limestone, dolomite, quartzites and phyllites.
Liangar Formation	Carbonaceous shales and phyllites.
Raghunathpalli Formation	Conglomerates, quartzites and slates.
——————Unconformity——————	
Iron Ore Group	Schists and phyllites

As stated above, the rocks surrounding the Gangpur Group were taken as belonging to the Iron Ore Group. Later work by Mahalik (1987) on the rocks immediately lying to the south of Gangpur Group and as far south upto Bonai established that the metasedimentary rocks in this area really do not belong to the Iron Ore Group. They are much younger to the Iron Ore Group and the Bonai Granite. They consist of a sequence of arenaceous, carbonaceous and argillaceous formations and closely resemble the Gangpur in their lithology, structure and metamorphic history. They were classified into a new lithostratigraphic group designated as "Darjing Group" by Mahalik (1987). The basal conglomerates in this group contain pebbles of banded hematite jasper and granite.

The stratigraphic succession of the Darjing Group as suggested by Mahalik (1987) is presented in Table : 3.

Table-3

Stratigraphic Succession of Darjing Group

Gangpur Group	Rudaceous, carbonaceous, calcareous and argillaceous metasediments.	
	Disconformity	
Darjing Group.	Intrusives....................	Quartz vein, Basic and ultrabasic dykes
	Jalda Formation..........	Staurolite schist with bands and lenses of calc-schist and calc - gneiss garnetiferous schist.
	Kumakela Formation.......	Carbonaceous phyllite and slate, banded carbonaceous quartzite.
	Birtola Formation..........	Felspathic quartzite and conglomerates, green schist, conglomerate and greenish quartzites. Basal conglomerate and quartzite.
	Unconformity	
	Bonai Granite	Granites and gneisses
	Iron Ore Group	Quartzites

Critical examination of the sedimentological, tectonothermal and igneous history of both Gangpur and Darjing Groups indicates very close similarity between them making one to believe that they were deposited in a single basin under similar depositional environment with a sedimentary break in between representing a disconformity. They were later deformed and metamorphosed simultaneously during Satpura cycle. Darjings and Gangpurs can now be taken as belonging to one group with the Darjings depositing earlier than the Gangpurs. The assemblage is characterised by a repetitive sequence of rudaceous, arenaceous, carbonaceous, calcareous and argillaceous sediments having basic volcanics within as sills. They have undergone tectonic deformation in several phases with a typical E-W to ENE - WSW tectonic trend and are metamorphosed to staurolite grade. They show features of shearing, probably related to Singhbhum thrust and retrograde metamorphism towards the later part of their geological history. It is likely that the Singhbhum thrust has affected both the Darjing and Gangpur rocks at their base.

It is surmised that after the Iron Ore craton stabilised, marginal shallow tectonic basins were formed to the north and northwest and iron free sedimentation took place continuously over a greater part of the Proterozoic Era over the eroded surface of the Iron Ore Group and Bonai Granite to be followed by sedimentation of the Gangpurs. Fig. 3 shows the geological map of both the groups in the regional geological set up.

Kolhan Group

The Kolhan Group comprising basal purple sandstones and conglomerates overlain by limestone and slates is exposed in Singhbhum region in the form of an elliptical outcrop stretching in a SSW direction from Chaibasa to north of Noamundi. The rocks of Kolhan Group having gentle dips along the south eastern margin of the outcrop rest unconformably over the Singhbhum Granite. They become increasingly more deformed along the north eastern margin where they come in contact with rocks of Iron Ore Group. Pebbles in the conglomerate derived from Singhbhum Granite and banded hematite jasper of the Iron Ore Group indicate that the Kolhans were deposited over a basement of Iron Ore Group and the Singhbhum Granite. They are believed to be equivalent of Darjing group but are not deformed and metamorphosed as observed in the Darjing group. A small exposure of rocks in Kunjar plateau in Sundargarh district is believed to be similar to the Kolhans. The Kunjar plateau presents a circular feature.

Newer Dolerite Dykes

Dolerite dykes, in small to large exposures are found extensively in the Singhbhum granite body. They have two important trends : NE - SW and NW -SE. The longest dyke known as Palaspanga dyke extends from Chaibasa in Bihar south-westwards to Keonjhar over a length of about 100 kms.

Other Igneous intrusives in North Orissa

Several other small unclassified intrusive bodies are found, such as Tamperkola granite, a small granite body intrusive into Darjing Group and Sundargarh granite another small granite body associated with the Gangpur Group of rocks.

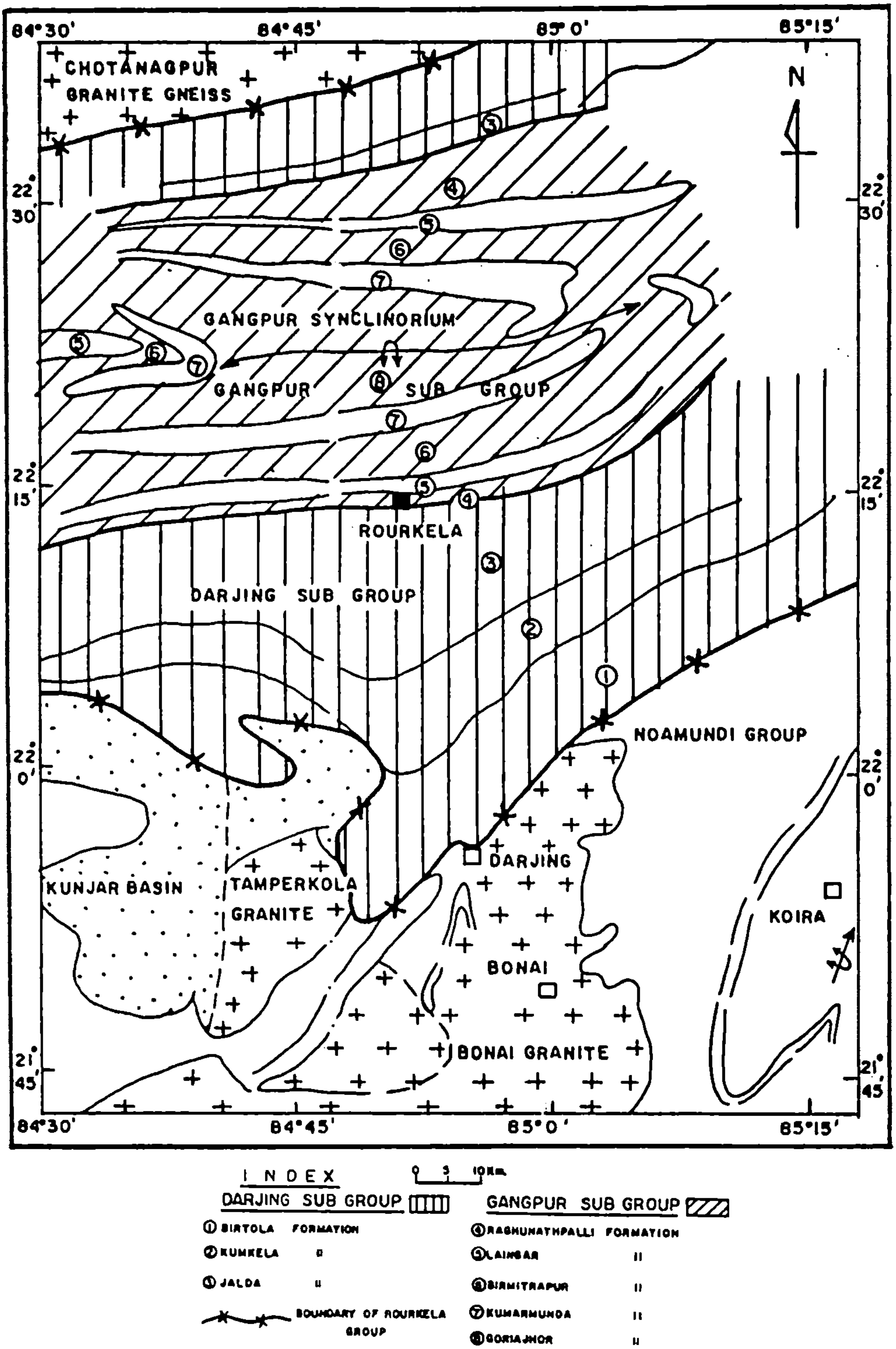

Fig.3. GEOLOGICAL MAP OF ROURKELA GROUP.

Undifferentiated granite gneisses

Extensive granite gneissic rocks occur around Kamakhyanagar, Pallahara, Rengali, Deogarh and Kuchinda areas of north Orissa and deserve more attention. Mahalik (1994) believes the Pallahara Kamakhyanagar gneiss (Palkam Gneiss) as the basement of BIF sequences.

2.2 South Orissa (Sector - II) : Eastern Ghats Mobile Belt

The Precambrian rocks of south Orissa occur extensively in the south eastern part of the State. They are abruptly terminated against the north Orissa craton along Brahmani river valley by a series of east-west trending faults (Mahalik 1994). Three boundary faults (lineaments) limit them along their northern, western and eastern margins. An important inlier of these rocks occur to the west within the western sector (sector III). The rocks of south Orissa are different in their lithology, structure and metamorphism and igneous history compared to rocks of either North Orissa or West Orissa sectors. They constitute a high grade granulite facies metamorphic terrain. The whole assemblage of rocks are designated as Eastern Ghat Super Group after the Eastern Ghats geomorphic terrain which they compose. Based on recent tectonothermal and geochronological studies the rocks are believed to have evolved in a mobile belt of the mid-Proterozoic period., though the parent materials could be of Archaean age.

2.21 Lithotypes

The most important rock formations are the meta-sedimentaries (khondalites, quartzites, calc-granulites, crystalline limestones and garnet biotite schist etc.), meta-igneous rocks (basic granulites, charnockites, wide variety of granite gneisses and augen gneisses). Both the meta-sedimentaries and meta-igneous rocks have been migmatised to leptynites, charnockites and composite gneisses etc. The intrusive rocks are represented by a variety of granites, gneisses, anorthosites and alkali syenites. The meta-sedimentaries and the meta-igneous rocks occur either as independent bodies or are interwoven with each other in the field.

Khondalite

Khondalite forms a very prominent suite of paragneissic rocks through much of the Eastern Ghats Mobile Belt and are intimately associated with charnockite, calc-silicate rock, crystalline limestone, quartzite, garnet biotite schist and mafic granulites. They occur extensively in high level areas (+700 m above mean sea level) forming well developed bauxite plateaus as in parts of Koraput, Kalahandi, Phulbani districts or in low level lateritic peneplains adjacent to the coastal plains in parts of Ganjam, Puri, Cuttack, Khurda and Dhenkanal districts.

Calc-silicate rocks.

Calc-silicate rocks are found interbanded with khondalites. They mainly comprise of diopside granulite and diopside scapolite granulite.

Crystalline Limestone.

Crystalline limestone occurs interbanded with khondalites as seen in Khariar area (Kalahandi district). They form potential source of limestone deposits for commercial exploitation. A typical carbonatite rock is found within the Eastern Ghat rocks in Sunki valley of Koraput District.

Basic Granulite

It is a mesocratic to melanocratic, coarse grained and equigranular rock found interbanded with khondalite, charnockite etc. They are believed as the metamorphic equivalents of mafic igneous rock produced by volcanic activity during the sedimentation of khondalite host rocks.

Leptynite

Leptynite refers to foliated quartz-felspar-garnet rock that lacks sillimanite but may contain biotite and minor hypersthene. Generally leptynites are adjacent to khondalites forming border phases between khondalite and charnockite or khondalite and migmatite. Primary leptynites are apparently absent. A peculiar interbanded association of white leptynite and greyish charnockite occur in Chandpur area of Puri district (Kar, 1989). It is believed that the charnockites are migmatised into leptynites along well developed bands, streaks and lenses.

Charnockite

Ever since charnockite was first defined, its nature and genesis have been the subject of controversy. They have formed by many processes singly or in combination, either as metasomatic products, igneous intrusion, migmatisation or by metamorphism (Park & Dash, 1984).

The charnockites are usually conformable with mafic granulite and members of khondalite suite. They may also be found as metasomatic or anatectic veins.

Migmatite

A variety of composite gneisses occur west of Berhampur in Digapahandi area. They are good source of dimension stones in Orissa.

Augen gneiss

Augen gneisses occur in many part of South Orissa. They have not been properly studied and dated. They occur widely in low level areas around Sonepur, Baudh, Angul, Meramundali, Parjang and Digapahandi etc.

2.22 Intrusive rocks in the Eastern Ghats Belt.

Anorthosite

Anorthosite is an important intrusive rock in the Eastern Ghats belt and occurs at three specific areas : (1) east of Bolangir (2) Angul and (3) Chilika Lake (Balugaon, Rambha) area.

A very big circular anorthosite body is exposed around Bolangir, Tarabha, Salebhata and Luisingha occupying an area of around 1000 sq. km. This rock underlies vast stretch of peneplains with a thin cover of black soil. Small outcrops of anorthosite occur near Angul. The Chilika lake suite covers an area of more than 1200 sq. km. They are well seen in the bald rocky hills around Balugaon, Banpur and Rambha along the western margin of Chilika lake. It may be pointed out that these anorthosites lie very close to the boundary faults/lineaments on the west, north and eastern sides of the Eastern Ghats Belt. They are probably tectonically controlled intrusive bodies. The Chilika anorthosites have been dated as 1400 My by Sarkar et al (1981).

Nepheline syenite

Several nepheline syenite outcrops are seen in the Eastern Ghats Belt of Orissa. The important occurrences are near Koraput, Khariar, Samal and Redhakhol (Panda et al, 1993, Sahu, 1976).

Granite

Several undifferentiated granite intrusives are found in many localities within the Eastern Ghats Belt. They are not properly mapped nor correlated to the lithotectonic set up.

2.23 Type Areas

Four type areas in the Eastern Ghats Belt have been chosen to present the important lithologic units. These are 1) Areas between

Berhampur and Jeypore; 2) around Angul, 3) around Rengali Dam Project and 4) around Khariar - Gandhamardan-Bolangir. The last one strictly comes under sector III (West Orissa).

(1) Eastern Ghats between Berhampur and Jeypore in Ganjam and Koraput Districts

The occurrences of Eastern Ghats rocks between Berhampur in Ganjam district and Jeypore in Koraput district , over a distance of 300 km. have been discussed by Nanda and Pati (1989). The rocks are divided into three dominant lithotypes, reckoned from west to east (i.e. from Jeypore to Berhampur), viz, (1) a basal pyroxene granulite-charnockite belt, (2) central khondalite belt and (3) the upper granitic migmatitic belt with enclaves of khondalite, basic granulite and charnockite. The central khondalite belt is associated with extensive bauxite mineralisation.

(2) Angul Area

The rocks around Angul are an intimately interbanded assemblage of sillimanite garnet gneiss (khondalite), calc-silicate granulite, quartzite, basic granulite, garnetifeous quartz felspathic gneisses and felspathic augen gneisses (Halden et al, 1982). All are tectonised and mixed with quartz felspathic neosomes which pervade and obliterate parts of all other rock types. Two important products of neosome invasion are leptynite (quartz-feldspar-garnet) and charnockite (quartz-felspar-pleochroic hypersthene). These rocks have a typical Mahanadi trend (WNW-ESE).

(3) Rengali area

North of the Gondwana basin, the Eastern Ghats rocks occur in close proximity with the rocks of Iron Ore Super Group (Deogarh and Malyagiri BIF assemblage). The rocks have a general E-W trend (Mahanadi trend). These consist of several parallel bands of coarse quartzites with rounded muscovite and occasional fibrolite, garnet biotite schist (physically resembling rusty brown khondalite), thin banded basic granulites, migmatised pink, grey and striped gneisses with development of charnockites and leptynites from the pre-existing gneisses. Unlike other areas of Eastern Ghats belt, khondalite (sensu stricto) is missing here and its place is taken by coarse quartzites and garnet biotite schists. Charnockitisation of orthogneisses is a common feature in this area.

(4) Khariar-Gandhamardan-Bolangir

The rocks in this area have a semicircular outcrop and are detached from the main Eastern Ghats body. They appear to be engulfed in a gneissic country. The semi-circular pattern gives the impression of a NW-SE trending fold closure. The closure can be connected to the NW-SE trending rocks of Nagavalli-Vansadhara and Mahanadi Brahmani valleys on either side. Peculiarily these rocks contain graphite deposits (Acharya & Dash, 1984). The rocks consist of crystalline limestone (around Khariar), khondalite (Gandhmardan hill), calc-granulite (Bolangir) and Proterozic intrusives such as anorthosite (Bolangir) and nepheline syenite (Khariar).

2.24 Major Structures and Structural trends.

The Eastern Ghats Belt is bounded by several major faults/ and lineaments to its west, north and east. The western boundary running from the southern tip of Orissa to Sambalpur shows an abrupt geomorphic and geophysical (Bouger gravity) discontinuity. A thrust along the western boundary of the Eastern Ghats has been confirmed by deep seismic sounding (Kaila & Bhatia 1981). The northern boundary is characterised by a series of west to east faults in which both the rocks of Eastern Ghats Belt and North Orissa craton are involved. These faults are designated as North Orissa boundary fault by Mahalik (1984, 1994). It runs approximately from Sambalpur in the west to Jaraka on the east, a distance of about 300 Km. The eastern boundary of the Eastern Ghats is very likely another major lineament along which they abruptly meet the coastal alluvia. The anorthosites of Chilika lake area occur along this lineament. Mahanadi river, which has an east-west course between Sonepur and Naraj appears to flow along a significant lineament. It is along this lineament, the Mahanadi trend of the Eastern Ghats rocks i.e. ESE - WNW abruptly meet the typical Eastern Ghats trend i.e. , NE-SW. There are two more faults running parallel to Vansadhara and Nagavali river courses in Koraput district. They have a NW-SE trend which cut across the normal NE-SW strike trends. These faults are parallel to NW-SE tectonic trends as shown in the map (Fig.-2).

Major folds are rare in the Eastern Ghats. One mappable fold closure is seen around Kapilas hill in Dhenkanal district. The northern limb of this fold has been truncated by the North Orissa boundary fault. Major north easterly plunging folds are seen around Chhatia.

Three important structural trends are observed in the Eastern Ghats rocks. The earliest of them is the typical NE-SW trend. It is well seen in the coastal tract from Koraput through Ganjam, Puri and Cuttack district. The next important structural trend is the NW-SE trend (Nagavalli trend) well seen in the coastal tracts of Ganjam and Puri districts. It has affected the NE-SW structural trend. Another important structural trend is observed along Mahanadi valley between Sonepur and Naraj. It is the Mahanadi trend which varies from E-W through ESE-WNW to NW-SE. It may be synchronous with the Nagavalli trend as mentioned above.

It is noticed that the structural trends, major thrusts and fold pattern have some genetic connection e.g. (1) The NE-SW structural trend is closely parallel to the western and eastern boundary faults. These are the oldest structures. These structures have, it appears, some influence on the intrusion of Bolangir and Chilika lake anorthosites. (2) The NW-SE structural trend, the Vansadhara and Nagavalli faults represent the second phase of deformation. This has probably given rise to the arcuate outcrop seen in west Orissa sector. (3) The ESE-WNW Mahanadi trend, the north Orissa boundary fault and the Kapilas fold closure are well related structural features. They may be either a third phase or are synchronous with the second phase features as mentioned above. These features are probably related to intrusions of anorthosites (Angul) and nepheline syenites (Samal, Redhakhol).

2.25 Metamorphism.

The rocks of Eastern Ghats Belt represent a high grade metamorphic suite. The temperature -pressure condition of metamorphism in Eastern Ghats Belt can be visualised from mineral paragenesis. Absence of muscovite and characteristic presence of K-feldspar and sillimanite suggest the temperature of formation of granulites to be around 700°C. Cordierite-hornblende bearing assemblage (around Angul) may be included under low pressure granulite facies (Temp. 600°C and Pr. 5.5 kb).

2.26 Age and evolution of Eastern Ghats Belt (EGB) rocks.

There is great controversy as to the age of the major and important rock formations of the EGB. In South India, major granulite facies metamorphism occurred about 2600 My and it is believed that khondalites and associated rocks were formed earlier to this age. It was previously believed that the granulite facies rocks of EGB were of this age. Recent age data showed a very young age (mid-Proterozoic) for the granulite facies metamorphism. The age of Chilika anorthosites have been dated as 1400 My by Sarkar et al (1981) which is believed to be equivalent to the granulite facies metamorphism in this tract. Recent dating by Aftalion et al (1988) on a variety of rocks of Angul area (augen gneiss, quartz felspathic gneiss, leptynite and pink granite) shows ages between 1040 Ma and 914 Ma. Sarkar et al (1989a) studied granitoids of Harabhangi dam area near Adaba and obtained Rb-Sr-isochron age of 870± 46 Ma. They have (1989b) also shown a late Proterozoic alkali magmatism in the Eastern Ghats Belt during 900± 100 Ma. Many of the radiometric dating data from the Eastern Ghats terrain of Andhra Pradesh and Orissa sector indicate a pronounced late Proterozoic (900± 100 Ma) event with some vestiges of late Archaean age for the protoliths (Paul & Ray Burman, 1986). No definite Archaean dates are available on any rocks in the Eastern Ghats. However the EG group of rocks are held to be Archaean and older than the Iron Ore Super Group rocks by many early workers.

According to Naqvi and Rogers, (1987) the geological history of the Eastern Ghats Belt appear to contain the following significant events: (1) The oldest activity was the deposition of silty and shaly sediments (now khondalites), carbonates (now calc-silicates and crystalline limestones) and intercalated basic sills and lava flows (now mafic granulites). (2) Major E-W compression caused the prevailing NE-SW strike in the belt. Several stages of compression probably occurred. Granulite facies metamorphism probably accompanied one or more of these deformational events, associated with metasomatism and CO_2 fluxing etc. The ages of deformation and metamorphism are not well established but they might have coincided with the emplacement of granites and anorthosites during the middle Proterozoic. (3) Following main compression cross folding on E-W axis at about the same time as emplacement of anorthositic and related magmatic suites took place. The Chilika lake anorthosite massif (1300-1400 Ma) has been proposed to be synchronous with the cross folding. (4) Intrusion of alkali magmas and possibly dolerites followed in the late Proterozoic period.

2.27 Stratigraphy.

The stratigraphic sequence of the south Orissa rocks is not well established nor its relation with the rocks of north Orissa known with certainty. Several stratigraphic sequences have been proposed by early workers such as Chatterjee et al (1964), Narayanswami (1975), Parthasarathi et al (1975), Murthy et al (1971) and Balasubramanyam & Chatterjee (1975).

The following tentative sequence is suggested

Table - 4
Tentative Stratigraphic Sequence in Eastern Ghat Belt

Development of neosomes, migmatisation, formation of leptynites, charnockites, nepheline syenites etc.	Late Proterozoic
Intrusion of granites, anorthosites, etc. during second fold movement accompanied by granulite phase metamorphism, development of major faults, development of mobile belt.	Middle Proterozoic
Major fold movement giving rise to the prominent NE-SW trend with granite intrusion.	Late Archaen to Early Proterozoic
Formation of khondalite and basic granulite parent materials.	Archaean

2.28 Contact Between Eastern Ghats Belt and Singhbhum North Orissa Craton

Recent studies by the author reveals that the contact between the Eastern Ghats Belt and the Singhbhum-North Orissa Craton is characterised by a wide zone affected by several east-west running faults (Sukinda fault of Prasad Rao et al, 1964 a,b and North Orissa Boundary fault of Mahalik, 1984) with fault fragments of both blocks interfingered with each other. The stratigraphic relation between the two cratonic blocks has been obscure because of intermingling of the fault slices and concealment of the contact by granitic intrusion, Gondwana sedimentation and lateritic cover. However, it is interpreted that the Eastern Ghats rocks evolved earlier than the Iron Ore bearing rocks of the North Orissa craton and these two at their contact got fragmented into slices by a series of east-west running parallel faults, Mahalik (1994).

2.3 West Orissa (Sector - III)

The West Orissa Sector forms the south eastern fringe of the Bhandara craton (Fig-4) and is typically different from the Eastern Ghats Belt to its south east and North Orissa-Singhbhum craton to its north east. It is more complex and less studied than the other two sectors. It is characteised by the presence of Proterozoic sedimentary basins besides the Archaean supracrustals and intrusives which are incident

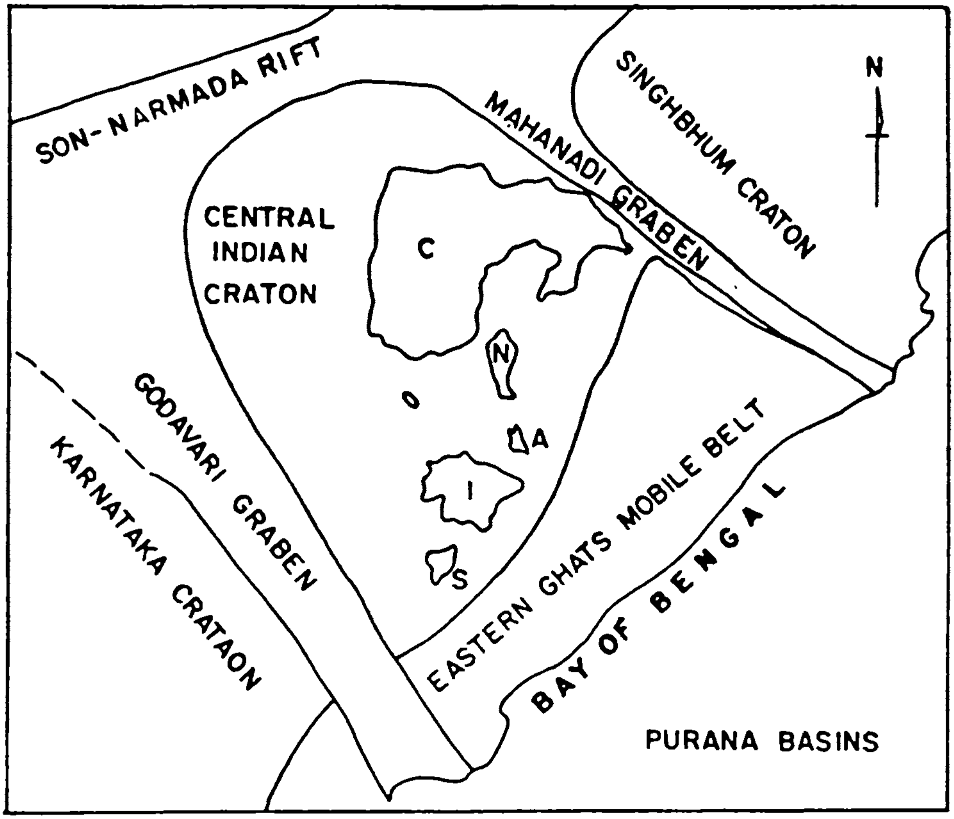

Fig.4. Tectonic Framework of Purana Basin in Bhandara Craton

C-Chhatishgarh basin, N-Nawapara Khariar basin

A-Ampani, I- Indravati, S- Sukma,

(After Ramkrishnan, 1987)

either in Singhbhum craton or within the Eastern Ghats Mobile Belt. It is bounded to the north east by Mahanadi graben, to the southwest by Godavari graben and to the southeast by the western boundary fault of the Eastern Ghats Mobile Belt. Economically this area is also important with occurrences of bauxite (Gandhamardan), limestone (khondalite association at Khariar, Proterozoic sedimentary association at Dungri, Kotpad, Kottameta), tin deposits within granite intrusives, graphite in khondalites at Sargipalli and gemstones in the various intrusives. Naqvi & Rogers (1987) have given the following stratigraphy of the area modified after Crookshank (1963).

Table - 5

Stratigraphy of West Orissa.

Puranas (Cuddapah & Vindhyan)	Upper	Limestone, purple shale, slate
	Lower	Sandstone, shale, quartzite, grit, conglomerates.
	Unconformity	
Igneous intrusives	Dolerite dykes Granite and pegmatite Charnockite Greenstone and granite gneiss	
	Unconformity	
Eastern Ghats Group	Khondalite	
Bailadila (BIF) Group.	Banded hematite quartzite, quartzite	
	Unconformity	
Bengpal Group	Multiple schist, and gneiss containing andalusite : basaltic flows	
Sukma Group	Quartzite, schists and gneiss containing sillimanite.	

The relation between different rock groups as shown in the table above is not thoroughly established. The division between the Sukma and Bengpal Groups is essentially based on differences in metamorphic grade. It is quite probable that the khondalite rocks so abundantly available in Kalahandi and Bolangir districts (Khariar, Gandhamardan etc.) are older to the Iron Ore formation (Bailadila Group). These Eastern Ghats lithologies could be placed together with the Sukma Group.

2.31 Distribution of Important Rock Groups.

Archaean Rocks

(1) Eastern Ghats Group.

An important circular outcrop of Eastern Ghats Group of rocks is seen around Bolangir town which is cut off from the main Eastern Ghat Belt to its south east by a variety of granitic and anorthosite intrusives. This circular outcrop is well observed in the satellite imagery (Fig. 2). The rocks consist principally of khondalite, crystalline limestone, quartzite and calc-granulite. These rocks form a significant plateau topography at Gandhamardan associated with rich deposits of bauxite. The rocks also carry economic deposits of crystalline limestone (Khariar) and graphite (Sargipalli, Sargimunda etc.,).

(2) Sukma Group.

Though Sukma Group is an important rock group of Bastar region (north west of Sukma) it is rarely found in West Orissa Sector. It consists of high grade rocks such as cordierite gneiss, pyroxene gneiss, diopside quartzite etc.

(3) Bengpal Group.

A significant outcrop of Bengpal Group of rocks is found in South Orissa immediately south of Indravati Proterozoic basin. The principal constituents of the Bengpal Group are andalusite bearing gneisses and schists. Basaltic and tuffaceous rocks are abundant in this Group.

(4) Bailadila Group.

A very small outcrop of Bailadila Group of rocks is observed in Hirapur hills. It consists of quartzite and banded hematite quartzite (BIF).

(5) Undifferentiated Granite and Granite Gneiss

A variety of granite and granite gneiss occur forming peneplains around Jeypore, Nawrangpur, Bhawanipatna, Bargarh and Bolangir. They occur at two distinct geomorphic levels 500 m-600 m above MSL around Jeypore-Nawrangpur and about 300 m above MSL in Kalahandi, Baragarh and Bolangir districts. The number and sequence of intrusives are not properly studied. Anorthosites are widespread east of Bolangir and are believed to belong to middle to late Proterozoic in their age. Numerous pegmatites traverse the granite gneisses and are believed to be the source of gemstones in west Orissa. Some pegmatites contain tin ore in Koraput district. Small occurrences of nepheline syenite also occur near Khariar. They are believed to be late Proterozoic in age.

Proterozoic Sedimentary Basins

Upper Proterozoic sedimentary sequences are characteristically found in this sector which are not seen in other sectors of Orissa State. They are found in scattered occurrences forming parts of Chhatisgarh and Bastar basins. They are seen at Hirakud (Chhatishgarh Group), Nawapara -Khariar plateau, Ampani, Kotpad (Indravati Group) and Kottameta (Sukma basin).

Details of the different outcrops are given by Ramakrishnan (1987), Murthy (1987) and Balakrishna & Mahes Babu (1987) in the Proceedings of the Seminar on Purana Basins of Peninsular India (1987). They all belong to the Upper Vindhyans. A brief description follows :

Hirakud Outcrop

Proterozoic sedimentary rocks are found on the south-western rim of Hirakud reservoir. They form the eastern margin of Chhatisgarh basin. The rocks contain an important horizon of limestone besides quartzite. The limestone is being mined at Dungri for the Bargarh cement plant. The limestone of Dungri are stratigraphically equivalent to the Raipur Group of the Chhatisgarh SuperGroup.

Khariar Plateau

It is a detached outcrop of the main Chhatisgarh basin forming a plateau on the border of Orissa State. It consists of an alternating sequence of sandstones and shales, equivalent of the Chandarpur Group. It is believed to cover diamond bearing kimberlite pipes now under investigation.

Ampani Outlier

It is a small exposure lying between the Khariar exposure in the north and the Indravati in the south. The rocks are similar to those of the Khariar highland.

Dutta (1963) believed them to be equivalent of the Vindhyans (Upper Kurnool). The rocks of Ampani 'basin' resemble the Chandrapur - Tiratgarh stages of Chhatisgarh - Indravati main basins. They consist principally of conglomerates, sandstones, siltstones, purple shales with calcareous intercalations.

Indravati Basin

It shows a late Proterozoic sequence of flat lying sandstone, shale, limestone and stromatolitic limestone. Ramakrishnan (1987) has given the following classification of these rocks (Table - 6).

Table - 6

Classification of Indravati Group After Ramakrishnan (1987)

Jagdalpur Formation	Purple shale with stromatolitic limestone.
Kanger Limestone	Limestone (Kotpad limestone)
Cherakur Formation	Purple shale, Arkosic sandstone
Tiratgarh Formation	Sandstone.
———————— Unconformity ————————	
Archaean	Granites & supracrustals.

The Kanger limestone occurs as a major horizon near Kotpad, The rock exposed in Sabari River bed at Gupteswar cave are extensively stromatolitic.

Sukma Basin

Horizontal Purana sediments are found near Sukma lying further south of main Indravati basin. The stratigraphy of this occurrence is broadly correlatable with that of Indravati basin as given above. Rocks corresponding to Tiratgarh, Kanger and Jagadalpur formations are well developed. Limestone is widespread around Sukma, Kottametta and Kanjipani which have been investigated for their economic potential (Ramakrishnan (1972).

3. CONCLUDING REMARKS

The geology of Orissa in the three geographical sectors, viz; North Orissa, South Orissa and West Orissa is typically different from each other. In North Orissa, it is greenstone-granite association with banded iron formation, in South Orissa, it is the high grade granulite facies rocks and in West Orissa, it is the sedimentary basin of Purana age. In each sector, the rocks range in age from somewhere in Archaean to the Late Proterozoic. In North Orissa, it is claimed by some as containing the oldest rocks of sedimentary origin, around 4 to 3.8 billion years age. There is controversy about the age of different units of Banded Iron Formation and its relation to the granite intrusives. In South Orissa, the age of khondalites has not yet been determined. The origin of khondalites is also controversial from metamorphosed clastic deposits to materials in deeply weathered profiles (Dash et al 1987). The granites and gneisses of West Orissa need further study and dating. A tentative stratigraphic sequence for the three sectors is presented in Table-7.

Table - 7
Stratigraphic Sequence in the Three Sectors of Orissa.

North Orissa (Sector - I)	South Orissa (Sector - II)	West Orissa (Sector - III)
Sundargarh Granite Tamperkola Granite	Nepheline syenites Migmatisation Charnockitisation.	
Gangpur Group Darjing Group (Kolhan Group)	Granites Augen gneisses	Chhatisgarh and Indravati Group
Dolerite dykes Bonai granite Singbhum granite (Phase - II)	Anorthosites (Granulite facies metamorphism)	Granites
Noamundi Group (BIF III) Simlipal Group		Bailadila (BIF) Group
Singhbhum Granite Phase - I		
Deogarh-Daitari-Gorumahusani Upper Malyagiri-Tikra Group (BIF - II)		Bengpal Group
Lower Malyagiri Group (BIF - I)		
Pallahara-Kamakhyanagar granite gneiss (Palkam gneiss).	Granite gneiss	Granite gneiss
Rengali Assemblage	Parent materials of Eastern Ghats Group (Khondalite, Basic granulite)	Sukma Group, Eastern Ghats Group.
Older Metamorphic Tonalite Gneiss Older Metamorphic Group	Base not known	Tonalite Trondhjemite Gneiss.

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Gondwanas

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1. INTRODUCTION

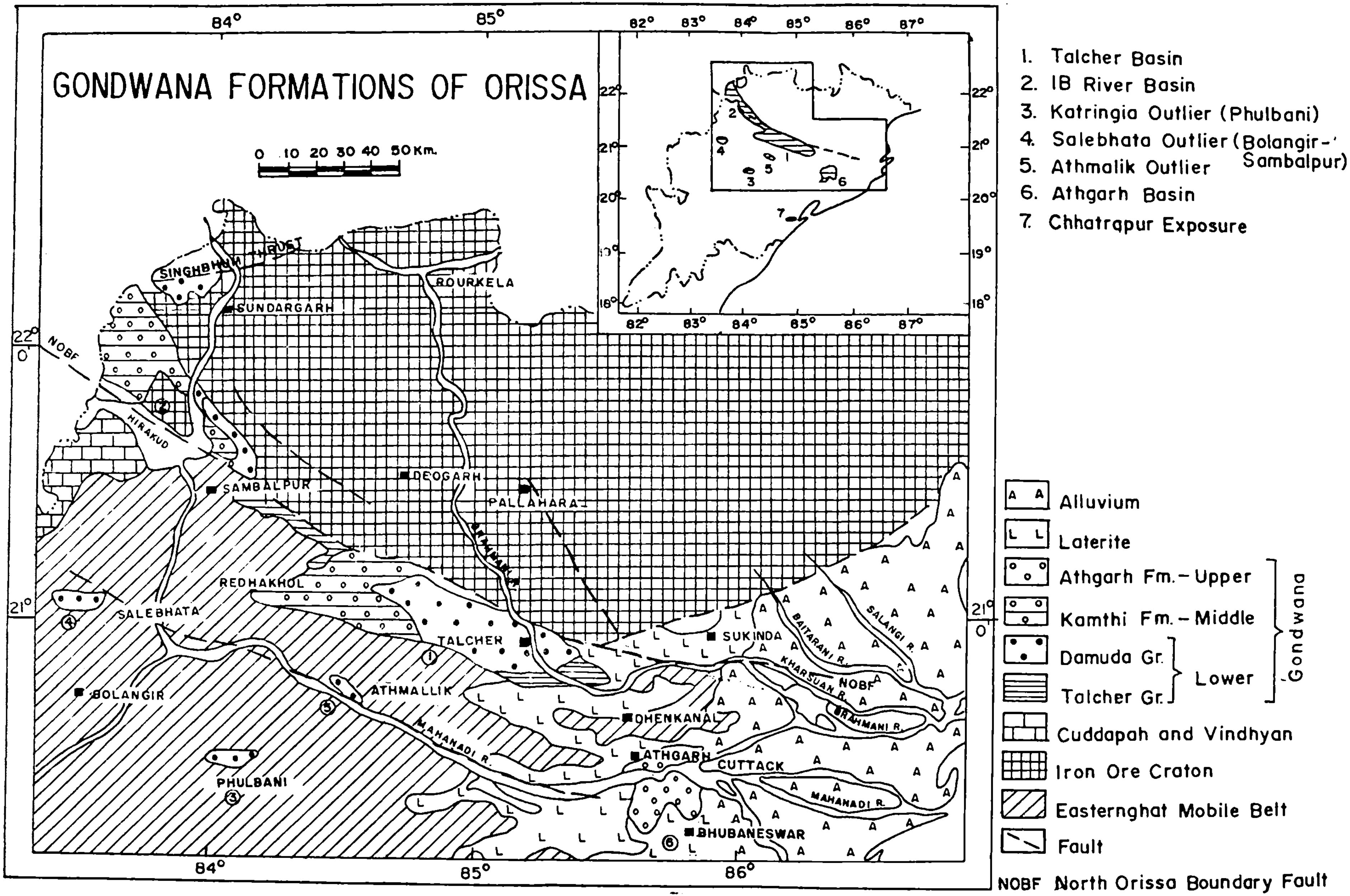
The term "Gondwana" was first used by Medlicott in 1872 to describe conglomerate, sandstone, shale and coal measures of fluviatile and lacustrine origin from Indian Peninsula, ranging in age from Upper Carboniferous to Upper Jurassic. The Gondwana lithic fill has been traditionally accepted as continental clastics with floral elements represented successively by *Glossopteris, Dicroidium* and *Ptilophyllum* dominated assemblages. A preserved thickness of less than a km to about 3 km points to varying rate of deposition and subsidence over a large span of time (e.g. 160-170 million years) punctuated by episodes of non-deposition depending on environmental and tectonic set-up of various depocentres (Ref : Recent Advances in study of Peninsular Gondwanas by GSI at 9th Intl. symp. on Gondwanas, Hyderabad, January 1994).

2. DISTRIBUTION

The Gondwana rocks occupy an area of about 12,400 sq. kms. in Orissa (Refer map enclosed). Their basin-wise distribution is as follows :

Table - 1

Sl.No	Basin/Outlier	District	Geological Age
1.	Talchir Basin	Angul/Dhenkanal	Upper Carboniferous-Triassic (300-200 m.y)
2.	Ib River Basin	Sambalpur/Sundargarh	-do-
3.	Katringia Outlier	Phulbani/Baudh	Upper Carboniferous-Permian (330-275 m.y)
4.	Salebhata Outlier	Bolangir /Sambalpur	-do-
5.	Athmallik Outlier	Angul/Phulbani/Baudh	-do-
6.	Athgarh Basin	Cuttack/Khurda	Lower Cretaceous (140m.y)
7.	Chhatrapur Exposure		Ganjam/Puri -do- (?)



GONDWANA FORMATIONS OF ORISSA

Karharbari Formation

Attaining a thickness of 270 m. in Talchir and 90-125 m in Ib River sections, the Karharbaris conformably overlie the Talchirs and are composed of fine grained micaceous sandstones, cross-bedded arkosic sandstones; coarse, pebbly, ferruginous felspathic sandstones and lenses of conglomerate (Das & Rath, 1974; Das, 1994).

Barakar Formation

It is the main coal bearing horizon in Orissa. The Barakars have attained a thickness of 500m in Talchir basin and 600 m in Ib River basin. Graded bedding of the chiefly arenite sequence demonstrates deposition -cyclothems, each terminating with shales, carbonaceous shales and coal seams. Talchir recorded 10 cycles while the Ib basin hosts 5 coal seams in Rampur sub-basin and 3 seams in Hingir sub-basin. Boulder beds composed of boulders, gravels, cobbles of quartz and quartzite characterise the basal part of the formation. Presence of carbonaceous shales in the outliers of Phulbani, Bolangir and Athmallik have been indicated.

Kamthi Formation

A thick sequence of conglomerate, sandstone and shale overlying Barakars are grouped together as the Kamthis. These have a thickness of 250 to 300 m. The members extend from Permian to Triassic in age (Raja Rao, 1982).

Athgarh Formation

Comprising dominantly of sandstones classified as quartz arenite, sub-lithic arenite, lithic arenite and lithic wackes (Mishra, 1988; Pal, 1990) characteristically lacking in feldspars in the clastic components, Athgarhs attain thickness of upto 400m, and include conglomerates and grits, carbon shales, variegated shales and fire-clay; most of them as small lenticulars, breaking the monotonous vastness of sandstones. Only at Naraj, a dolerite intrusive (109 + 26 m.y. by K-Ar method; Agrawal & Rama, 1976) punctuates the near homogeneous rock exposures. The sandstones have a typical laterite profile upto a level of 60 m above the M.S.L. A recent palynology study in splintery khaki-green shales from Garh Haldia, underlying the Athgarh sandstone indicates a Lower Gondwana age (Tiwari et al, 1987).

5. STRUCTURE

The Gondwana sediments of Talchir and Ib river basins were deposited in the Satpura-Mahanadi graben, defined by pronounced NW-SE trending lineaments on a Precambrian platform, almost separating the Eastern Ghat Mobile Belt and North Orissa craton (Mahalik, 1994). The northern and southern boundaries of the two basins are faulted and the sediments appear to have been preserved in the troughs.

On a regional scale, Talchir basin takes the shape of a north westerly plunging syncline with closure in the east and the younger horizons outcropping progressively towards west (Raja Rao, 1982). On the other hand, the beds dip northerly and number of coal seams increases in that direction, indicating a possible homoclinal structure. Three sets of intrabasinal faults trending E-W, NE-SW and WNW-ESW have been recognised.

The Ib river basin which consists of three sub-basins, viz. Rampur, Hingir and Talabira has been affected by two sets of intrabasinal faults trending NW-SE and E-W.

The younger Athgarh Formation rests unconformably over Eastern Ghat granulites with a dip of 3°-10° to S&SE directions. The Gondwana sediments of Phulbani, Athmallik and Bolangir also rest unconformably over Precambrian basement.

6. CLIMATE & SEDIMENTATION

The earliest period of glaciation as interpreted with the Talchir Boulder Bed (Blanford et al, 1856) switched over to warmer phase towards the end of the Talchir times as evidenced by stromatolitic limestones and marl (Pandya, 1987). Thus, the Gondwana sedimentation was possibly initiated in a post -glacial warm climatic condition. By the Kamthi period, ferruginous red beds indicated almost a sub-arid climate and the sandstones thereafter may be interpreted as the indicators of a warm and humid time, facilitating diverse flora without extensive coal measures.

Sedimentation environment during the Talchirs indicates lacustrine deposition in rift-controlled lakes (Pandya, 1990); adorned with a north to northwesterly palaeocurrent pattern, indicating Eastern Ghat granulites as the immediate provenance (Das, 1994). Rejuvenation of boundary faults in the Damuda period changed the basin configuration with braided and meandering streams flowing due NW and deposition in this fluvial regime under tropical warm-humid climate resulted in the coal formation extensively. Eventual filling up of receptacles, sub-basin making and arid deposits of the Kamthis confirm the shallowing of the basins.

The drought in the basins, enhanced through vertical oscillations, may have reversed the trend in the Orissa sector of the Gondwanas, till the Lower Cretaceous. The vertical oscillations could have resulted in yet another deepening of the basins with south-easterly palaeo-drainage this time. Another warm and humid tropical phase of climate with braided streams on moderate to high ground-slope led to the massive deposition of the Athgarh Basin (Adyalkar, 1965; Kumar & Bhandari, 1973; Mishra & Pandya, 1991). The sedimentation tectonics of the outliers in Phulbani - Bolangir-Athmallik, however, have a different story to tell perhaps of isolated intermontane basins in Permo-Carboniferous having their own independent sedimentation history.

7. GONDWANA PALAEONTOLOGY

Developed as continental sediments in fluviatile / lacustrine systems, the Gondwana palaeontology is a great storehouse of luxuriant plant fossils though animal remains by and large are confined to post-Damuda rocks. A secluded sector such as in Orissa, where the Gondwanas have a missing link between the lower Triassic and Lower Cretaceous, the faunal assemblage is almost insignificant. Palaeobotanical work has brought to light several successive floras; the older Gondwanas showing abundance of *pterodosperms, ferns* and *eqisetales;* grouped together as *Glossopteris* flora while the younger Gondwanas contain *cycads* and *conifers* collectively called as *Ptilophyllum* flora. In fact, it was on this basis that a two-fold classification of the Gondwanas was suggested (Fox, 1931) in spite of an already existing three tier system (Vredenburg, 1910) devised basing on the mere equivalence to Permian, Triassic and Jurassic systems of Europe. The current thinking is reverting back to the old threefold system of Lower, Middle and Upper Gondwana once again. The specifics of the new three fold classification based on fossils are as under;

Lower Gondwana Assemblage

The Permo-Carb fossils in Orissa are *Glossopteris indica*, browniana, *decipiens, longicoulis, Gangamopteris cyclopteroids angustifolia, Vertebraria, Schizoneura, Sphenopteris, Cladophleb* & so on. Mohanty (1966) reported similar flora from Phulbani with some petrified wood-stems of unknown affinity. Bolangir and Athmallik outcrops have not yet yielded any fossils.

Middle Gondwana Assemblage

The Permo-Triassic Kamthis from Talchir and Ib basins have yielded *Glossopteris indica, conspicua, stricta, browniana, communis, retifera, Vertebraria indica, Gangamopteris angustifolia, Schizoneura gondwanesis* etc., but the upper parts of this formation looks much similar to the classical Mahadeva Group of a much younger status and also is suspected to contain vertebrate and fish fossils, though none has been recovered till date. Hence this is a somewhat transitional palaeontology which is now recognised on an all India feature as discrete from the typical spectrum of either the older below or the younger above; though Orissa's representation is imperceptible locally.

Upper Gondwana Assemblage

Mega plant fossil yield of Athgarh sandstone indicates a typical Ptilophyllum flora comprising *Martiopsis macrocarpa, Cladophlebis indica, Rhizomopteris balli, Thinfeldia, Cycadites, Ptilophyllum, Otozamites* etc. Though other Gondwana exposures from the East Coast have invertebrate fossils, none have been recovered from Orissa thus far.

8. Economic Mineral Deposits

Coal, fire clay and building stones have been the main minerals and rocks of commercial importance. In fact, the Orissa coal reserves estimated so far in Talchir and Ib amount to 46.5 billion tonnes, which is 23% of the all India reserve,. Plastic as well as nonplastic fire-clay in Cuttack, Khurda, Jharsuguda and Sundargarh districts form good refractory bricks. Sandstones of Orissa temples and laterites of Orissa buildings have all been the raw materials derived from the Gondwana Supergroup.

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Tertiary and Quaternary

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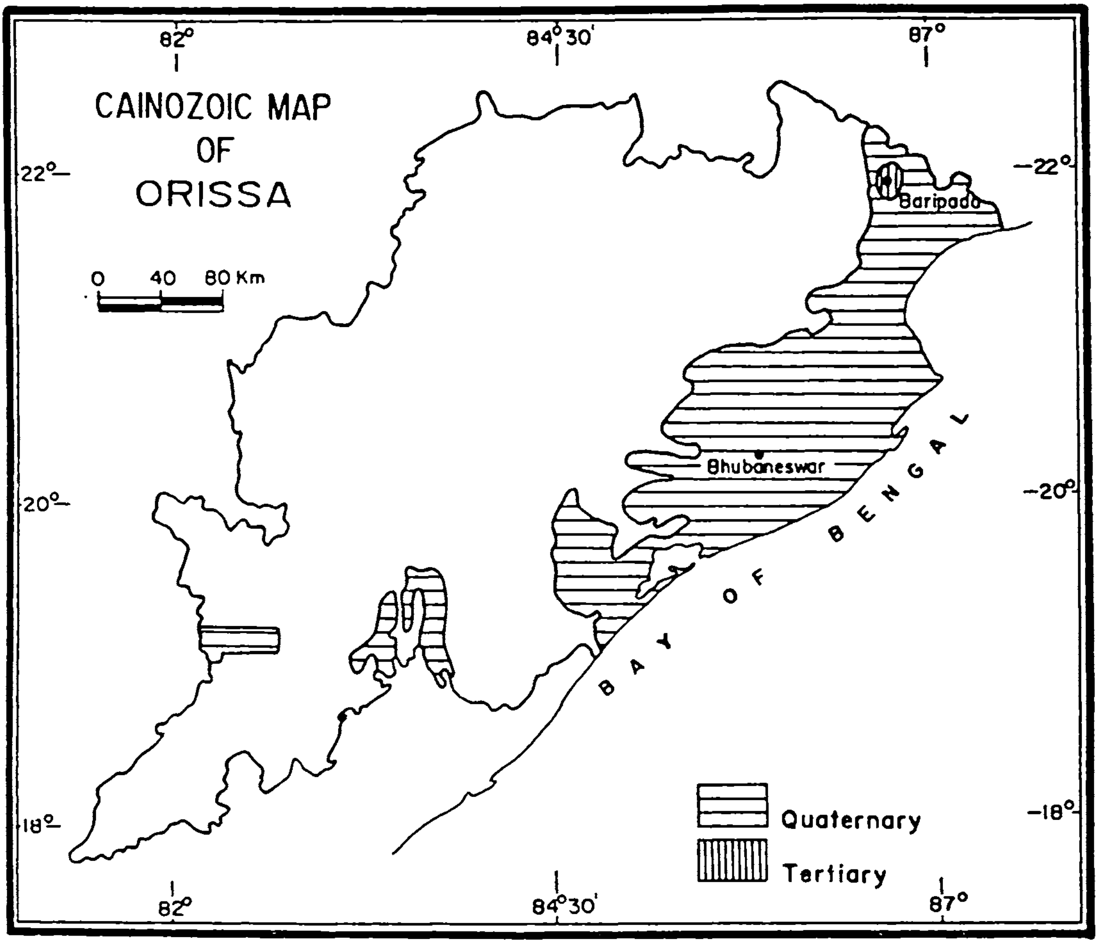
1. INTRODUCTION

The Cainozoic Era is very important for it was during this period, the Himalayan range was upheaved to its present position and the present triangular shape of the Indian peninsula was carved. It witnessed establishment of angiosperm flora and foraminifera as well as proliferation of mammalian fauna. The Tertiary formations have been the host of our oil and gas reserves. Quaternary is marked by the appearance and evolution of man.

Development of the Cainozoic geology in Orissa overlying the Pre-Cambrian (with or without the Gondwanas intervening) is reflected in the small patch of Tertiary strata, often referred to as Baripada Beds with Mio-pliocene (or Neogene) biota and of over 53 m. of thickness near Baripada. In spite of the meagre onshore outcropping, existence of subcrops of a full succession from Jurassic to Holocene have been established at all the four major coastal depressions, namely at Paradeep, Cuttack, Konark and Chandbali and in fact continues onto the offshore area (Bharali et al, 1991). Surficially, an area of 30,381 sq. km. of coastal tract, veeing into the inland riparine deltas store the Cainozoics, of which the study of Tertiaries commenced early in the century and that of the Quaternaries, late in the sixties (Mishra, 1993). A map showing the Tertiary and Quaternary formations is enclosed.

Complementing the sedimentary beds under discussion, both from the Tertiary and the Quaternary, sedentary formations of the same age but lying over erosion surfaces carved in rocks of all ages; laterite columns / profiles have been developed and the process of formation is perhaps continuing into the present times, both as ' High-level' types as well as ' Low-level' types (less than 600m aMSL). While the former is often the weathered, modified and residual product of reconstitution in situ, the latter type is often detrital, though there are local cases of low-level residual laterite zones. A few occurrences in field may show an admixture of the sedentary and detrital; with the total profile developed, i.e. the hard pan on top, the lithomarge below, the decomposed bedrock yet below and the partially altered rock forming the local basement; thickness-variation in layers notwithstanding. The characteristic property of soft when dug afresh but getting hardened on exposure, makes the


82°
84°30'
87°
CAINOZOIC MAP
OF
ORISSA
0 40 80 Km
22°
20°
18°
Baripada
Bhubaneswar
BAY OF BENGAL
Quaternary
Tertiary

laterites (literally brick stones), most sought after building stones in coastal Orissa country-side.

For a ready appreciation of the age limits and the divisions and subdivisions of the Cainozoic rocks, the classification has been given as under :

Eon	Era	Period	Subperiod	Epoch	Age (Yr x 10^6)
Phanerozoic	Cainozoic	Quaternary	Holocene	Recent	Present time
				Subrecent	0.01
			Pleistocene		1.80
		Tertiary	Neogene	Pliocene	5.00
				Miocene	22.50
			Palaeogene	Oligocene	37.50
				Eocene	55.00
				Palaeocene	65.00

Hence the geological coverage of the rocks upto 65 million years before present, stretching over the coastal tracts and the deltaic outwash plains of the rivers and rivulets draining into the Bay of Bengal forms the target area for the ensemble discussed herein.

2. TERTIARY

As mentioned earlier, the only rocks of Tertiary cropping out namely the 'Baripada beds' have very limited spread-out, within a radius of 8 km. around Baripada in Mayurbhanj district. Discovered on the Budhabalang river bed by Bose (1904) at Molia (3.2 km to the south of Baripada town), the stratigraphy could be worked out from the well section near Chandua (22°06' : 86°45') by Pattanaik & Gupta (1971) as a set of stratified clay and sand with semiconsolidated clay, ferric grit and capped by ferruginous soil cap. At places, marly clay or limestone interbands are seen. Significant fossil contents comprise *Ostrea sp.* like *Crassostrea gajensis, Vredenburg* (index fossil of Lower Miocene), fragmentary lamellibranch close to Rotalia *beccarii, Linn;* smaller foraminifera, *ostracods,* fish-tooth, fossil wood fragments of *Palmoxylon* and *Shoreoxylon.* Bharali et al (1991) recorded extension of Baripada Beds southward upto south of Balesore with a dip of 4°-5° due south in their drilling data and thence it goes below laterite cover of Pleistocene - Holocene age. Equivalent Tertiaries from Chandbali offshore comprise medium-grained foraminiferal limestone with dolomite and occasional interbands of shale or sandstone. Other sub-basins of Paradeep, Cuttack and Puri-Konark are argillaceous. Waterworn specimen of the lamellibranch *Paphia sp* (Sahni, 1934) was obtained from Puri foreshore confirming Middle to Lower Eocene age contrasting with a Miocene age for the Baripada Beds.

3. QUATERNARY

From a limited marine sub-basin scenario of Tertiary, the land and sea scenario of the Quaternary landscape developed scope for widespread marine depressions on aggrading coast and consequently receding shoreline concomitant with the Recent to Subrecent terrestrial regimes mainly comprising a riparine domain with occasional punctuations of lakes or estuaries. Hence the agencies of erosion and deposition such as rivers, waves, wind have *sired* the Quaternary beds, at various points of space and time. They have not been continuously formed at one continuum so as to result in a distinct order of superposition in any significant scale. Their classification poses certain problems which have been further complicated due to climatic fluctuations on account of worldwide glacial and interglacial periods accompanied by lowering and raising of the eustatic levels *sans* fluctuation of the strand line. Tectonism and volcanic eruptions too have their own roles in formation and preservation of the terraces. It is worth mentioning of the ash beds resulting from the Toba volcanic caldera of Indonesia, some time 74,000 years before present (B.P.) making a major Late Pleistocene tephra, under the geological name of Youngest Toba Ash (YTA) and established both in Vansadhara - Nagavali and the Mahanadi - Brahmani river deltas (Acharya & Basu, 1993).

Devdas & Meshram (1991) have attempted to prepare a generalised stratigraphic overview for the fluvial deposits for the inland and upland river basins. Working in the deltaic and coastal regions, Roy et al (1988) have built up morphostratigraphic units (viz. erosional surfaces) for the fluvial regime and correlated them with their marine counterparts to evolve some standard, while the aeolian deposits have still eluded any status and have not found any place in the stratigraphic column; for these minus the ash beds, form mostly a case of redistribution of sediments within the other depositional environments without distinct large-scale occurrences, forming independent mappable units in a regional scale.

Geomorphology at the Quaternary onset, deriving the Tertiary signature of subsurface oceanic spurs out from the land; automatically has accreted the sub-basins of Chandbali, Paradeep, Cuttack and Puri-Konark, from north to south along Orissa coast and the Quaternary deposition thence have been deep enough though merging with the valley head clastics of the rivers which bore the materials to drop into the deltaic receptacles in the natural process.

The stratigraphic succession proposed by Devdas & Meshram (1990) is , as follows for the Quaternary deposits :

Present Day (Recent) Formation	Flood-plain outwash and channel deposits.
Bankigarh Formation	Semiconsolidated and loose older deltaic deposits of sand and clay
Kaimundi Formation	Partially consolidated and flood plain sandy clay deposits (caliche bearing)

— — — — — — — — Paraconformity / Disconformity — — — — — — — —

(?) Colluvial - Alluvial fill	Reddish sandy clay with calcrete

— — — — — — — — Paraconformity / Disconformity — — — — — — — —

(?) Naira	Sandstone, gravel / pebble beds, associated with the YTA ash bed

— — — — — — — — Paraconformity / Disconformity — — — — — — — —

Bolgarh Formation	Laterite and latosol by and large

— — — — — — — — — — — — — Unconformity — — — — — — — — — — — — —

Tertiary and older rocks

3.2 Inland Quaternary Rock Units

Occurring at the upper reaches of most river-basins, sandstones, the oldest Quaternary deposits are often the major geological indicator of environment. Together with YTA beds of similar marker characteristics of 74,000 years before present the Quaternary lithostratigraphic column shows enough indication of the environment of deposition. Lithologic details are given in the following paragraphs :

In Vansadhara riparine domain, a semicompacted and ferruginous, coarse to medium-grained sandstone having lensoidal pebbly horizons or pebble/gravel beds towards the bottom with gritty or mottled sandy-clay/clayey-sand horizons towards the top, occur near Naira village (19°13'05" : 83°46'20") of Koraput district. It is a cross-bedded sandstone, 8 m in thickness and of reddish to yellow -brown hue. Outcrops are found near Kharling (with lateritic hard pans), Gurhari, Kinjunagurha and Bisam-Cuttack (locally conglomeratic). In Nagavalli Basin, it is seen at Hati-Patharkhal waterfall (19°09'12" : 83°25'52"), Jagannathpur and J. K. Pur. In Indravati basin, it occurs south-southwest of Demkelar. In Mahanadi Basin, it is found south of Baudh and extends continuously upto Sonepur. In Brahmani basin, it is seen at Bijigola, Samal Barrage and Tumugola. In Sabari basin, thick cross-bedded sandstone underlain by grey clay and overlain by brownish sandy clay, occur near Jeypore. As a semicompact reddish sandstone as well as small gritty bands in Saptadhara nadi area In Rushikulya basin, it is found near Sorada. In Baitarani Basin, it occurs in the area contained between south of Anandapur and north of Similia (Devdas & Meshram, 1991).

Stratigraphically significant YTA beds comprise uncemented pyroclastic material consisting of fragments mostly <2 mm dia. Mostly well-sorted, nonplastic and light in weight (specific gravity 2.23), the ash bed on a broken surface is chalky white but turns tinted on weathering. It can write like a white chalk and absorbs plenty of water. Consisting of isotropic, angular to very angular glass shards and pumice, the ash bed has identifiable mineral phases like quartz, biotite and feldspars. Platy shards predominate over cuspate shards with rare pieces of long needle - like fragments (Pele's hair ?). The size ranges of glass shards in some noteworthy tephras are, as follows (Basu & Biswas, 1991)

Demkelar tephra	0.10 to 0.02 mm
Hati-patharkhal tephra	0.18 to 0.02 mm
Goguparhu tephra	0.30 to 0.02 mm
Kareni tephra	0.12 to 0.06 mm
Pittamohul tephara	0.23 to 0.03 mm
Sonepur tephra	0.25 to 0.02 mm

SEM study of tephra from Kareni (19°12'35" : 83°47'27") and Gogup-arhu (19°09'38" : 83°40'00") indicates that the ash bed cosists of angular to very angular shards and pumice fragments. ; establishing its dry transport. During dispersal, tephra is subjected to aeolian fractionation of crystal and glass. Thus only large pumice, if any, may give clue to the bulk composition of the erupted magma. The whole ash components show Fe enrichment, Al-Ca depletion and minor variation of alkali. Light rare earth elements (LREE) tend to be fractionated, where as heavy rare earth elements (HREE) may indicate a gentle reverse slope. The Orissa samples show uniform slope-down from La to Tb and a reversal i.e. slope-up from Tb to Lu (Acharya & Basu, 1993).

3.3 Deltaic and Coastal Quaternary Rock Units

The formational sequence constituted of Bolgarhs, Kaimundis, Bankigarhs and the Present have a lateritic setting at base, perhaps overlying Tertiary or older rocks with an unconformity. Physically distinct from the Naira sandstones, selectively placed inland, the Bolgarhs comprise low-level laterites and calcretes etc., lying coastal but accepted as marginally younger to the Nairas; for the calcrete-bearing brownish silt-clay overlying Nairas have been treated as parts of the Bolgarh formation.

Bolgarh Formation

Typically a laterite horizon mixed with coarse sand and clasts of varying dimensions, considerable part of the Bolgarh Formation is made up of residual soil and latosol, which are weathering products of the basement and duricrust respectively. Thickness of residual soil varies upto 3.75 m in thickness. Its marine equivalent, sometimes referred to in older literature as Oldest Coastal formation has been reported from around Satpara near Lake Chilika, as a long and narrow beach ridge consisting of highly oxidised reddish brown, medium to fine grained, well-compacted marine sand; associated with stable and well - dissected sand dunes consisting of similar sandy material.

Kaimundi Formation

Unconformably placed over the Bolgarhs, greenish grey to khaki-yellow hard clay and silt impregnated with calcareous concretions and occasional iron nodules describe the rock types of the Kaimundi Formation. It represents the oldest valley fill forming the highest terrace. Its marine equivalent, i.e., Oldest Coastal Formation with associated sand dunes are represented by yellowish brown, well sorted fine to medium grained sand; disposed broadly parallel to the coast line, with thin incipient soil development in upper parts of profile. Thickness of the Kaimundi Formation has been estimated at 3.5 to 8.5 m.

Bankigarh Formation

Bankigrah Formation occupies narrow flood plain along the major rivers, consisting of alternate layers of brownish silt and very fine white sand with intermittent mottled silty clay. The formation seems to have undergone very little induration and oxidation. In the upper deltaic portions, this is characterised by dark grey to brownish grey micaceous sandy-silt and silty-clay; whereas the lower deltaic component consists of greyish black sticky or hard, plastic clay with a little of fine silt and some carbonaceous material ingrained from recent umbrage of surface and its flood -trapped vegetational remains. Its marine equivalent termed as younger coastal formation comprises light yellow medium to fine-grained loose sand, deposited in a parallel configuration to the shore line. Thickness of the Bankigarh formation has been estimated between 4.35 m and 7.50 m.

Present Day Formation

The fluvial component of the Present Day Formation is made up of bed loads, channel bars, point bars and flood plains in major rivers showing coarse to fine and loose, poorly sorted, micaceous sand and clay. The marine equivalent is represented by pale yellow to off-white, medium to coarse-grained sand, including shells of living fossils; deposited with a coast - parallel configuration, associated with sand dunes. The lagoonal facies of the formation is characterised by sandy or muddy clay pile, with loose-bonded sandy particles with clays.

The Soil Cap

Yet another Quaternary member is the soil cover Residual soil on the Athgarh Sandstone Beds from Gondwanas show a typical yellowish-brown tint. Over the basic or metabasic rocks, soil is in shades of brownish yellow and brown but over the granitoids, soil is dark grey, off-white or white. On the khondalites, it is dark brown to cherry red but over the charnockites, it is of a lighter colour. Soil cover over the Kaimundis is khaki green to grenish yellow. Bankigarh soil cap is typically immature, porous, permeable and light yellowish-brown to light brown is appearance.

3.4 General Features of the Quaternaries

In spite of a generally low geomorphic profile and near-shore conditions of the Quaternary beds, certain marked features, viz. common fossil heritage, mesolithic - neolithic artefacts, predominace of selected heavy mineral assemblage are observed.

Fossil Riches

The more common vertebrate spectrum comprises bovines such as *Boselaphus sp., Cervid sp.;* canine fossils like *Cenis sp., Capra sp., Artiodactyla sp., Cervus duvacelii, Sus cristalus, Bos sp., Babalus sp.;*

antelope Cervicarpa sp.; invertebrate shells of *Ammonia becrarii, Cibicides sp., Bulimina sp.,* ; pores and pollens such as of acacia, palmae, graminae, chenopodiaecae, mabracae, osmudacae e.g. *Podocer sp., Pidites sp., Myriophyllum sp.* and fungal bodies of many types, all over.

Anthropological Remains

Various stone tools and earthern potteries indicative of the neolithic, have been recovered from the Kaimundi Formation. Some of he artefacts found are stone celts, earthen bowl with black polish, coarse grey ware, water vessels, lamp shades and bone tools from sharks like *Hemipristis* serra and Insurus pagoda, tools made of ray-fish e.g. *Raja Sp., Myliobatis* sp. (spine and dental plates) of tortoise/pupoise i.e. *Cybium sp., Denlix sp., Arius sp.* (from their pectoral spine).

Radiocarbon Dates

Available data suggests a radiocarbon age for the Kaimundi Formation as 4,250 ± 210 years B.P. to 58,80 ± 120 years B.P. while the same for the Bankigarh Formation ranges between 1,220 ± 120 and 1,590 ± 150 years B.P.

Heavy Mineral Assemblage

The common heavy minerals of the Quaternary sediments in Orissa include garnet, hornblende, sillimanite, ilmenite, rutile, monazite, epidote, tourmaline, cordierite, apatite, zircon, pyroxene, magnetite; both inland and off-shore.

4. ECONOMIC MINERAL DEPOSITS OF THE CAINOZOIC

In spite of the varying conditions of deposition and the prevailing vicissitudes of climate and environment during the Cainozoic, contribution to the economic minerals inventory during this era is significant; the most noteworthy being the colossal bauxite reserves (<1,300 mill. tonnes) evaluated in Orissa during the mid-seventies. China clay deposits (>100 million tonnes) on the residual concentration front like the bauxites and/or laterite building blocks or perhaps the lateritic ores of manganese, iron or gold (± PGE); may make up the sedentary domain of Quaternary ore/mineral deposits in Orissa. Sedimentary equivalents being mostly loose and unconsolidated, the rock formations do not form suitable receptables for mineral deposits but the placers of alluvial, colluvial, aeolian or marine nature such as the gemstones, tin, wolframite, black sands and so on list up the remarkable contributions from the Orissa Cainozoic.

Minor minerals in the Cainozic comprise building blocks of laterites, varieties of sands (filler, foundry, cement), lime shells, soil-clay of different types (potter's, Oil-mill and / or brick-clay or clay for rural construction and domestic wall-wash etc.). Groundwater potential abound in the Cainozoics.

The geological environments are suggestive of possible oil and gas reserves particularly within the off-shore Cainozoics; where depth of deposition is high.

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Geology of Offshore Orissa

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INTRODUCTION

OIL INDIA LIMITED has drilled 11 exploratory wells in Mahanadi offshore and adjoining North East Coast offshore area and 4 wells in Mahanadi Onshore area, so far. Apart from drilling, various surveys such as aeromagnetic, seismic, geochemical, 3D seismic, etc were also carried out. Area of operation of OIL in Orissa is shown in Figure 1.

Based on all the available data, the inferred geology of the offshore Orissa basin is described in this paper.

II. Tectonic Setting

The offshore Orissa belongs to a pull apart basin situated along the east coast of India. Paleogeographical reconstruction based on faunal and floral evidence suggests that India and Australia were connected together till the Upper Paleozoic. Break up of Gondwana land started during the Upper Paleozoic and was completed by the Upper Jurassic. The east coast of India represents the passive continental margin (Atlantic type) originated during break up of Gondwanaland. The offshore Orissa basin was formed at one of the three fossil tripple junctions identified along the east coast of India.

Based on the fault tectonics, the North East Coast basin in offshore Orissa can be broadly divided into four major sub-tectonic groups, namely graben area, flat platform area, region of carbonate build-ups and region of possible growth fault (Figure 2). Offshore Mahanadi basin contains two of these four tectonic elements (viz. the flat platform area and the region of carbonate buildups). Barring wells J (graben area) and K (growth fault area), all the wells drilled by OIL fall in the flat platform area or in the carbonate build-up region.

III. Structural Frame Work

A schematic geological section passing through the drilled wells connecting the onshore Mahanadi basin with offshore Orissa is shown in Figure 3. The position of the line of section is shown in Figure 2. As evident from the figure, the amount of the general southeasterly dip of the

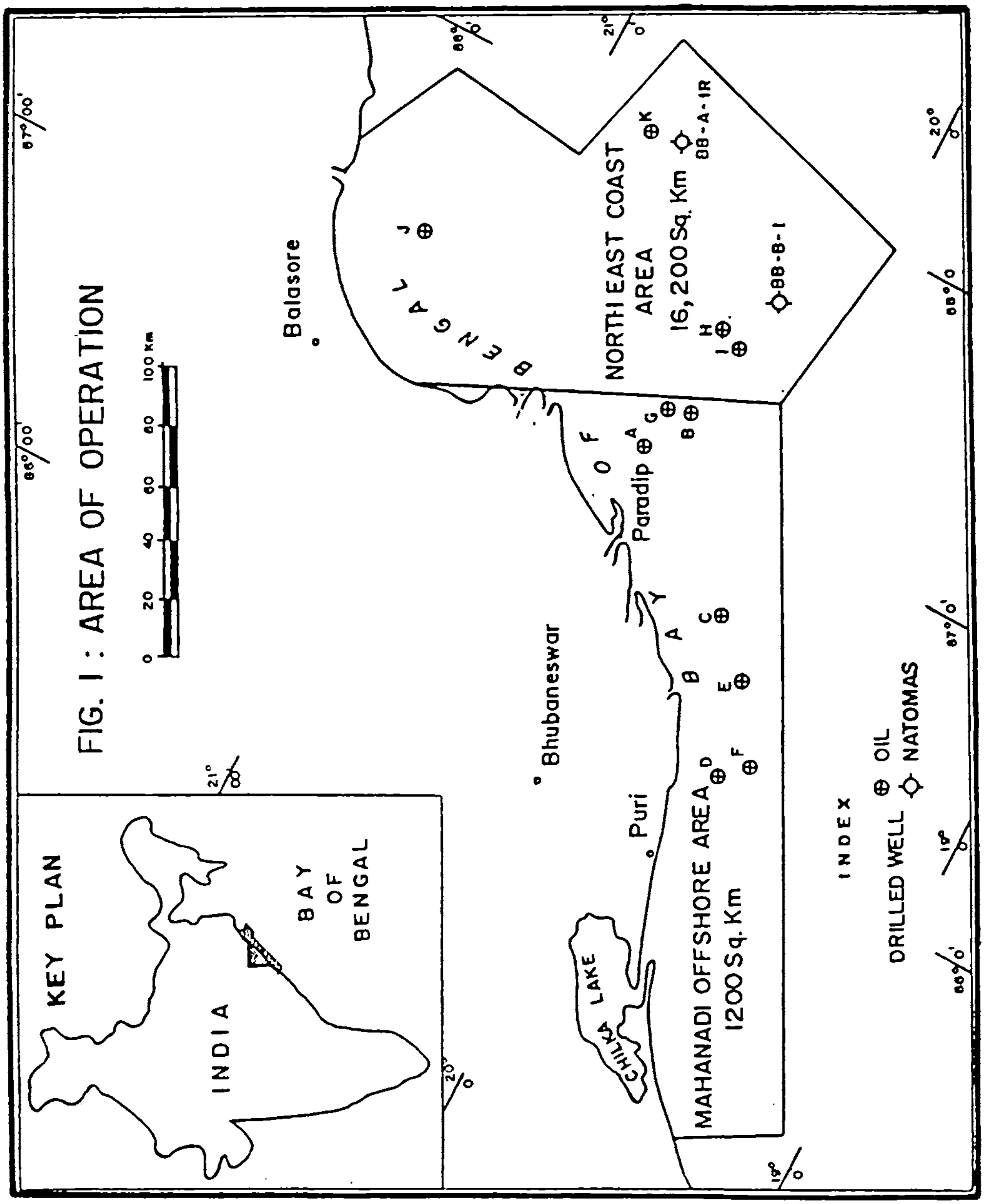
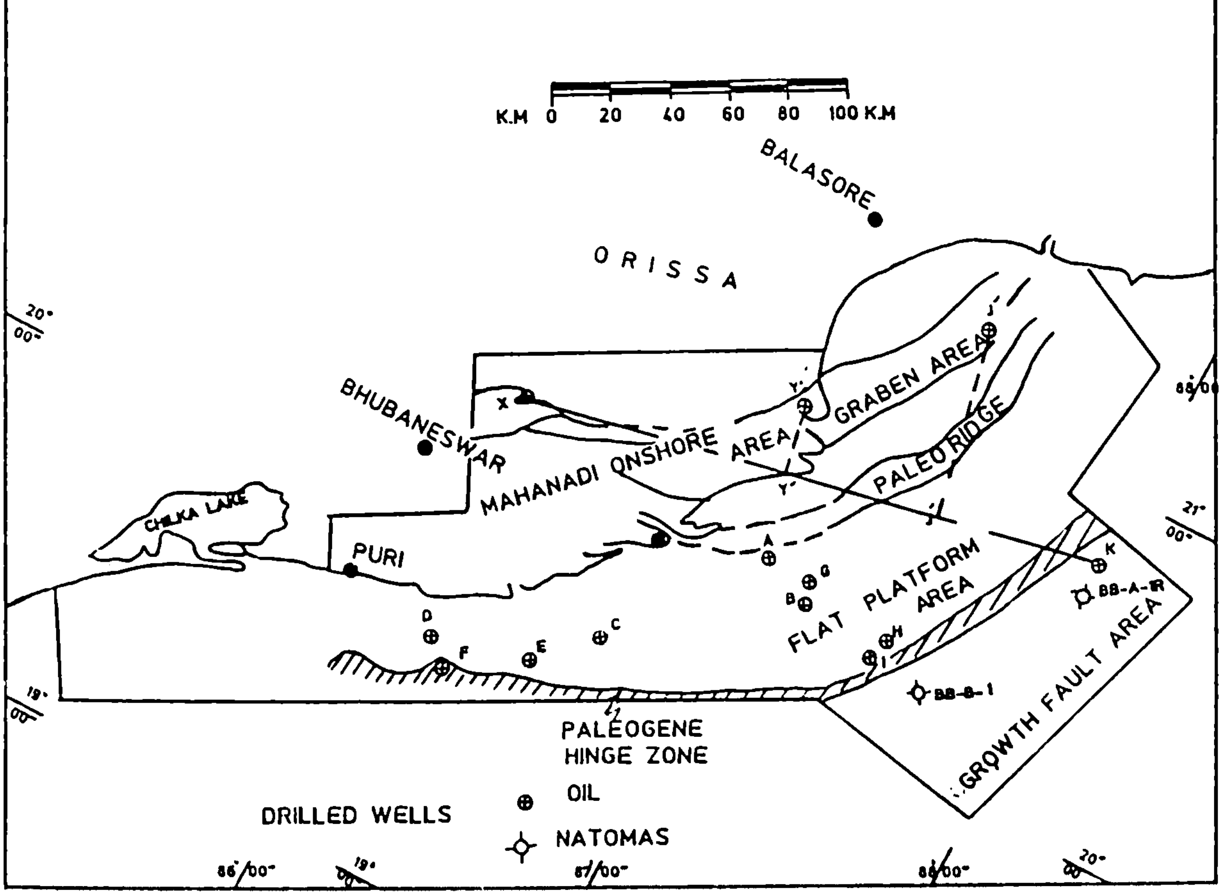


FIG. I : AREA OF OPERATION

FIG.2 STRUCTURAL ELEMENTS OF OFFSHORE ORISSA AREA



formations is low (2° - 3°). Near the shelf break, dip amount however increases. Being a tensional basin, the formations have been affected by a number of normal faults dipping towards the basin resulting in various tilted fault blocks. Majority of the faults are basement controlled penecontemporaneous type and are parallel to sub-parallel to the general NE-SW structural trend. Most of the faults present in the area are confined to the bottom sedimentary sequences and do not extend above the Eocene. Overall evidence indicate that in the Mahanadi offshore area, the Paleogene carbonates are affected by numerous faults whereas in the offshore NEC area the number of faults affecting the Paleogene sequence are very few.

Beyond the Eocene shelf edge towards the basinal side (i.e., towards east), a series of growth faults have affected the Upper Tertiary sedimentary sequence. These are related to high rate of sedimentation during the Upper Tertiary period which is confirmed by the presence of thick clay/shale sedimentary sequence (with interbeds of sandstone and siltstone) encountered to a total depth of about 4650m in the drilled well K.

In offshore Balasore area, a major graben has been mapped with possible continuation in the onshore Mahanadi area.

In general, folded structures are rare in the basin while faulted closures are commonly seen. Relatively speaking, structural closures are more in the Pre-Tertiary and Lower Tertiary sequences than in the Upper Tertiary sections. Significant folded anticlinal structures are however seen in the Mio-Pliocene section in the growth fault areas. No shale diapirs have been mapped in the area.

IV. Regional Stratigraphy of the Area

In the drilled wells, stratigraphic succession from Early Cretaceous to Recent has been encountered. The basement in the area is characterised by metamorphic rocks of Pre-Cambrian age. Generalized stratigraphy of the Orissa offshore basins are shown in Table - 1.

FIG.3 SCHEMATIC GEOLOGICAL SECTION PASSING THROUGH OFFSHORE AND ONSHORE WELLS

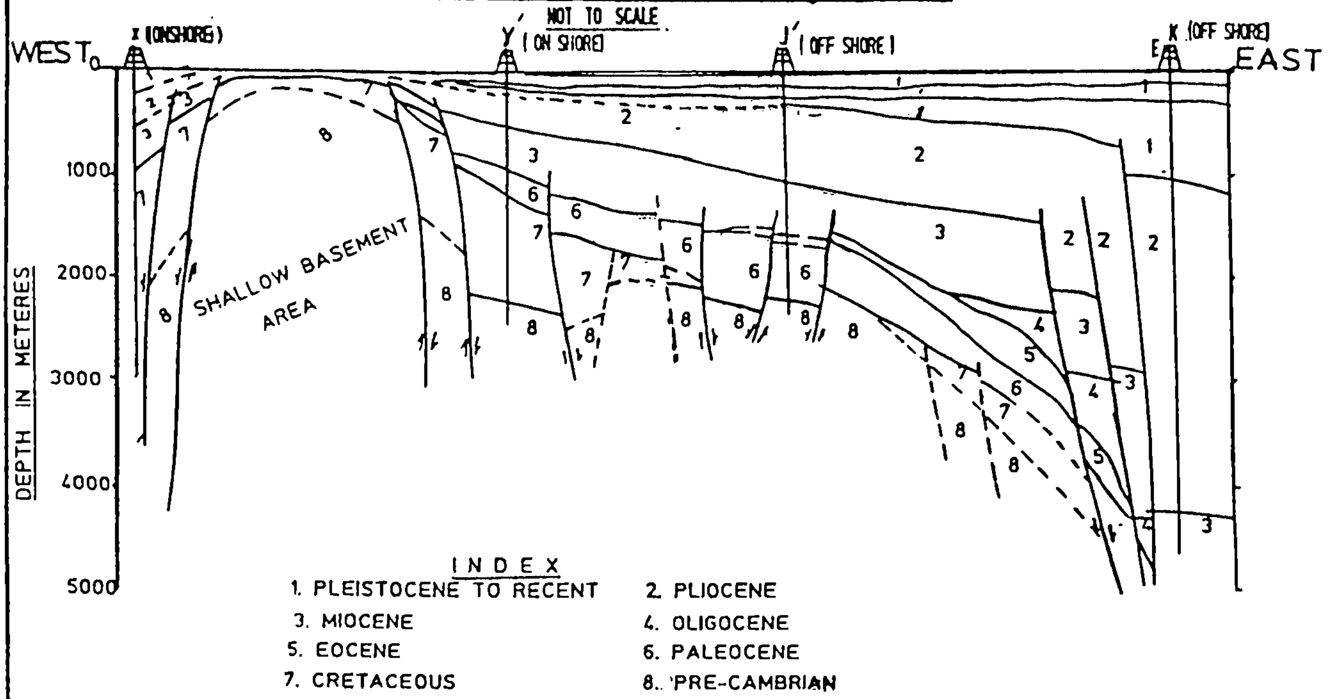


Table - 1
Generalised Stratigraphy of Orissa Offshore Basins

Age	Lithology	Environment	Maximum thickness encountered in wells (m)
Recent to Pliocene	Clay, claystone with few interbeds of sands.	marine and progradational deltaic.	4200
Up-Mid-Lower Miocene	Claystone, siltstone, shale with interbedded sandstone and limestone.	Progradational deltaic to deep inner shelf.	1903
Unconformity			
Oligocene	Claystone, siltstone, shale with interbedded sandstone and limestone.	Progradational deltaic to deep inner shelf to Bathyl.	576
Unconformity			
Eocene	Dark grey to buff massive limestone.	Inner to deep marine shelf.	772
Late Paleocene	Fine grained argillaceous limestone with interbeds of shale/sandstone.	Shallow supratidal to deltaic to middle shelf.	
Early Paleocene	Grey, calcareous shale with interbeds of glauconitic sandstone.	Deltaic/shallow marine	198
Unconformity			
Upper Cretaceous	Fine grained sandstone shales.	Marginal marine to Middle shelf.	293
Early Cretaceous	Tuffs and volcanics with minor interbeds of coal and carbonaceous shale and siltstone.	Continental	858
Unconformity			
Pre-Cambrian	Metamorphic Basement		

Overall evidence confirm that the strata dip more or less uniformly towards the southeast and the sedimentary sequence shows a general gradual seaward thickening. The important feature from hydrocarbon exploration view point is the presence of thick. sedimentary sequences in the area. Salient points of the major sedimentary sequences encountered in the drilled wells are summarily described as follows :

i) Basaltic flows of early Cretaceous age encountered in the wells confirm the presence of varying thickness of the volcanics.

Intertrappean shales and thin coal beds are present in the basin. Pre-trappean sediments in the area have so far been encountered in one well only (Well : G) drilled down to the basement. Quality of the seismic data below the volcanics is generally poor to authoritatively predict the presence/thickness of the pre-trappean sediments.

ii) A thick Paleocene sequence primarily consisting of dolomitic limestone with interbedded sandstone and siltstone unconformably overlies the Cretaceous sequence. In the north-eastern part of the Mahanadi basin, this Palaeocene section is wedge like in appearance with very poor development in well A.

iii) A thick carbonate sequence consisting of medium to coarse grained limestone with interbeds of sandstone and siltstone of Eocene age conformably overlies the Paleocene section. The significant feature is the increase in combined thickness of the Paleocene and Eocene carbonates towards the shelf edge as evident from the seismic profiles and well I. In well I, this section is represented by dark grey to black hard massive limestone sequence interbedded with black calcareous shales. The shelf margin carbonate build up present in the West Bengal basin in the north continues to the south in offshore NEC/MND basin.

iv) The seismic evidence clearly suggest that in the central part of offshore Mahanadi and in the southern part of offshore NEC, the Eocene shelf margin carbonates have been affected/ eroded by submarine canyons/channels (Figure 4).

v) The Eocene slope break in the basin is well marked on most of the dip seismic profiles. From the Eocene slope break, the thickness of the carbonate section gets considerably reduced towards the basinal side and finally looses its character suggesting a facies change.

vi) A very thick sequence of Oligocene and Miocene (both being separated by an unconformity) sediments consisting of siltstone/ claystones with minor sandstone unconformably overlies the Eocene carbonates in the drilled wells. The Oligocene sequence is however encountered in wells C, D & H and absent in wells A, B, E, F & G which may be due to erosional/non-depositional hiatus.

vii) A thick progradational sequence of Pliocene to Recent age consisting of sand (encountered in the upper part), grit and clays conformably overlies the Miocene sequence.

V. Environment of Deposition

The Pre-Cambrian basement in the basin is overlain by possible pre-rift Gondwana sediments. After prolonged hiatus, the entire area experienced outpour of basaltic lava flows in the Early Cretaceous time. These are correlatable with the Rajmahal traps. Drilling evidence so far indicates traps to be of aerial origin.

The formation of offshore Mahanadi/North East Coast basin began with deposition of Late Cretaceous sediments in a differentially subsiding basin in marginal marine environment. During Paleocene / Eocene, marginal marine to marine clastics were deposited in the south-western part and in near shore areas. Towards southeast (i.e., deeper basin) marine carbonates of equivalent age were deposited on stable shelf. These are platform type carbonates with build ups along the shelf edge (Figure 2). Building up of carbonates continued till early Oligocene period. However during late Oligocene-Lower Miocene period, the high influx of clastic sediments associated with basin subsidence had resulted in the cessation of carbonate depositions. These sediments were deposited in varying marine conditions.

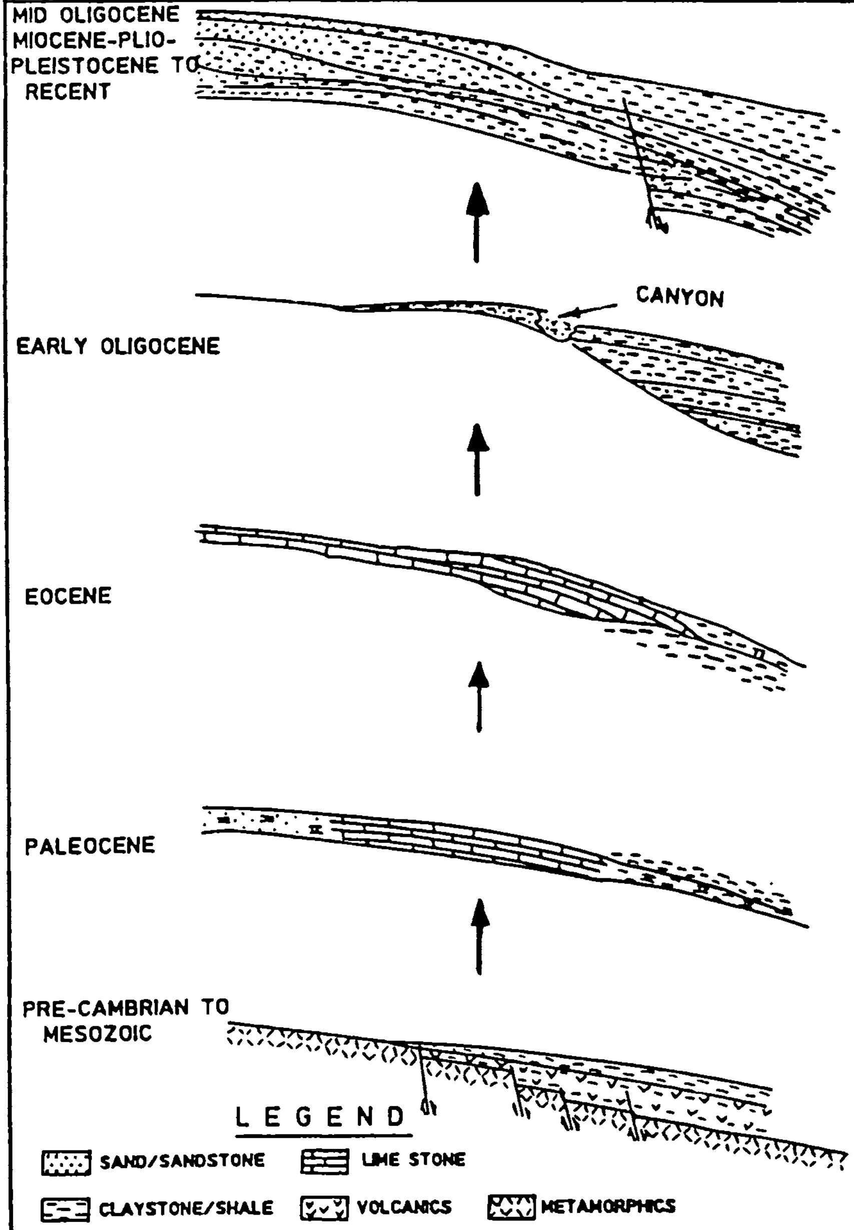
Since Mid-Miocene period, the basins have been receiving deltaic sediments from Mahanadi and adjoining river system. A series of progradational deltaic sequence have been identified in the offshore area. During the Neogene time the shelf edge fluctuated and the fluctuations was maximum in the northeast direction where it received large pile of sediments from the Ganga-Brahmaputra river system.

VI. Basin Evolution

The Mahanadi - NEC basin was initiated during the Upper Paleozoic with the deposition of continental pre-rift sediments. Later the basin experienced out-pours of basaltic volcanic rocks with inter-trappeans during the Early Cretaceous time. These intertrappeans are present both in the adjoining onshore depressions and in the offshore areas. The volcanic and the intertrappeans are essentially terrestrial in origin. The first significant subsidence and onset of major sedimentation and also marine transgression in the basin began in Late Cretaceous (around 83 my). The Late Cretaceous sediments covered part of underlying traps and granitic basement. The sediments were deposited under non-marine conditions in the peripheral part and in marine conditions in the proximal area.

Later on, over the gently sloping shelf of Upper Cretaceous period, marine Paleogene carbonates were deposited in a single upward shallowing (Late Paleocene to Mid Eocene) and later in upward deepening succession

FIG.4 SCHEMATIC DIAGRAM SHOWING STAGES OF EVOLUTION OF NEC OFFSHORE AREA
(NOT TO SCALE)



(upto Basal Early Oligocene). These carbonates are thickest over Paleogene shelf edge. Towards the basinal part, owing to sediments starving shale facies had developed during this period.

During the Late Oligocene -Early Miocene period (28-20 MY), the basin experienced a major regression and uplift followed by hiatus and erosion. In the Mid - Miocene period, the basin experienced both transgression and subsidence. The transgression reached as far as to the out-cropping Baripada beds. Middle Miocene and late periods witnessed rapid dumping of sediments through the recent Mahanadi Delta system which had resulted in the cessation of extensive carbonate deposition in the shelf area. Further to the east of the shelf area, the thick Mio-Pliocene clastic sediments were deposited over the Paleogene (shelf) sediments in a basin slope/basinal condition. Owing to the basinal subsidence and high rate of sedimentation, the Mio-Pliocene sediments in this area were affected by numerous growth faults.

Finally the Late Pliocene and Quaternary clastic sediments were deposited in the basin under fluctuating marine to marginal marine conditions. A schematic diagrams showing different stages of evolution of the basin through geologic time is illustrated in the Figure 4.

VII. Prospect

In view of non-discovery of commercial hydrocarbons in the drilled wells, a drilling pause was given after completion of drilling NEC # 4 and exhaustive geoscientific studies/surveys were carried out in the area during 1988-90 prior to any further drilling. Accordingly, the following geoscientific surveys/studies were carried out in the area.

a) Fresh 2D & 3D surveys in selected areas
b) Geochemical Sniffer Studies
c) Basin modelling studies

Based on the interpretation of all available data various prospects/ geological plays have been identified which are as below :

a) Bright spots anomalies within the Pliocene sequence in the growth fault area.
b) Oligocene clastic wedge-out resting on the Palaeogene hinge zone.
c) Porous intervals within the Palaeogene shelf edge carbonates.

Finally based on the studies indicated above, it has been decided to drill a 5000m well for Oligocene wedge-out prospect in North East Coast offshore area which holds reasonably good chance of having significant hydrocarbon prospects. Preparations for the next phase of drilling are in progress.

Acknowledgment

The authors are thankful to the management of OIL for allowing the publication of this paper. The views expressed in this paper are those of authors and are not necessarily of the management.

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Base Metal Deposits

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Geological Survey of India

INTRODUCTION

Though not an accredited rich state in terms of the base metal ore deposits, Orissa has three small deposits to its credit, at various stages of exploration and development. They are as follows :

Adash Copper	Proterozoic granulite	Sambalpur Dt.	Explored
Kesarpur Copper	Singhbhum Thrust zone	Mayurbhanj Dt.	Developed
Sargipali Lead	Gangpur greenstones	Sundergarh Dt.	Being Mined

Based upon total tectonic setting and geologic milieu, the Adash deposit makes a departure from the conventional belief of the charnockite-khondalite country rocks as generally barren of sulphide mineralization of significant size and grade. Kesarpur is the eastern tail end of the famous copper thrust of East and West Singhbhum districts in Bihar while the Sargipali galena deposit is the result of structural cum stratigraphic locii of mineralization.

For convenience of presentation, the three case histories are briefly outlined in the following paragraphs.

(1) ADASH COPPER ORE DEPOSIT

The copper prospect (21°23' 05" : 84°37'45") is situated at a distance 120 Km from Sambalpur R/s and can also be approached from Reamal on the Deogarh-Anugul N.H. 6, 30 km at the southwest.

Geological Set-up

Khondalite-charnockite suite of granulitic rocks in the Eastern Ghat Supergroup have leuco-granites and its variants emplaced discordantly as intrusives and resulted in kinds of granite gneiss and migmatites. The general strike of the country rocks is N60°E- S60°W to E-W and dips of 70° to 85° both to SE and NW. Affected by 3 generations of deformation, the rocks show F_1 folds as open isoclinals with north-south and subvertical axial planes. F_2 folds are gentler warps with varying plunges. The F_3 folds are tighter appressions with moderate to steeply plunging axes. Large transverse faults with dominant strike-slip movements affect the meta-chert beds in particular. A shear zone, varying in width from 20m to 70m and extending over a strike length of 650m along N60°E-S60°W in the Adash School Block is discernible.

Adash copper mineralisation is stratigraphically contained within the pyroxene granulite at and around the contact with granite gneiss; with the former as the footwall and the latter as the hanging wall but the structural preference is for the shear zones, particularly when it is coincident at the granite-granulite contact.

Details of Deposit

The deposit is a 3 lode system, of which the westernmost called as No. 1 is with a strike length of 650m while the other 2 are less continuous. Lodes are lenticular with chalcopyrite as the main ore with pyrite and pyrrhotite accessories (0.5 to 3%) while the enveloping surface comprises silicified pyroxene granulite palaeosome in granite gneiss. An important mineral association has been graphite, cropping out between Adash and eastward upto Butapali, over a length of 3 km, as small flaky zones of around 20-25% graphite (on visual estimate). In fact, footwall of Adash lodes is also graphitic migmatite and graphite zones have been intersected in many of the boreholes, at some depths or the other. Widths in the borehole cores have varied from 13.4m to 52m of graphite disseminations, analysing to be within 3.1-12.1% of Fixed Carbon.

Exploration Inputs

A total of 26 boreholes totalling 4,811.65m of core drilling has established copper mineralisation over a strike length of 1,600m. For operational convenience, the deposit has been divided into three exploration blocks, namely, School, Rampali and Mundasuni. Lodes have pinch and swell characteristics. Top oxidised zone is restricted to 40m from the surface. The depth-wise configuration of sulphide ore is typical of an 'Oxidation and Supergene level' upto 225m. on M.S.L. and the primary sulphide 60m below i.e. at around 165m.

Additional inputs in the form of 15 boreholes totalling 2,150m drilling were deployed at the eastern and western extension zones, but no significant copper mineralisation could be located.

Ore Reserves

Somewhat *en echelon*, the 3 lodes have hardly been together in any single cross-section. Estimation of reserves and average tenor are based on 2 cut-off grades, namely, 0.4% Cu and 0.8% Cu. The dimensions and range of Cu % of the 3 lodes are as under

Western Lode (No. 1)	700 x (2-21)m	Mostly Continuous	0.41 to 2.81% Cu
Central Lode (No. 2)	400 x (2-11)m	Continuous	0.20 to 2.27% Cu
Eastern Lode (No. 3)	50 x (1-3.5)m	Inconsistent.	0.72 to 1.17 % Cu

The 1st series of boreholes intersecting the ore down to 150m of R.L. have the degree of confidence suitable for classifying the reserves thence computed in the category of "Probable" reserves of ore, such as in the 'School Block', as distinct from possible continuation below this level, hopefully down to the 100m R.L., which has a relatively lesser assurance and hence categorised as "Possible" reserve. Rampali Block, on the otherhand provided no data to assume this supposed extension of ore below the lowest levels of intersection, viz, 150m R.L. and hence could not come out with any "Possible" reserve tonnage. On the above basis, reserve and grade computed are as follows

Name of Block	**Tonnage / Tenor : 0.8% Cu cut-off**	**Tonnage/Tenor : 0.4% Cu cut - off**
School	(Probable) 0.93 million tonnes / 1.46%Cu	1.81 million tonnes / 1.04%Cu
School	(Possible) Nil	0.60million tonnes / 1.04%Cu
Rampali	(Probable) 0.17million tonnes / 0.66% Cu	Nil

Although the segment of Adash Copper Deposit with 0.93 million tonnes is of 1.46%Cu grade, it is confined to a strike length of only 50m and depth of 125m (i.e. upto 150m of R.L.). It is a small deposit.

Beneficiation Characteristics

Batch scale tests indicated uniform copper sulphide distribution in almost all sizes but 70% sulphides liberated at 200#. Sulphide minerals comprised chalcopyrite and bornite with minor quantities of pyrite and pyrrhotite. Incidence of enargite, cubanite, mackinwaite and or scanty specks of gold have been recorded though rarely. Graphite is a close associtate in the nonmetallics but opaque association is with magnetite and ilmenite. Other gangue minerals in the aggregate are quartz, sphene and anatase.

Flotation tests with about 72.4% in <200# placed in a medium of 8.5 p_H consisting of Sodium diethyl dithiocarbonate collector and Pine oil frother, could raise a head grade of 0.76% Cu to 12.0%Cu upto 75% recovery level, However as graphite interferes with flotation, its separation through a Mozley Mineral Separator before putting into float cells were experimented upon and the results are, as follows:

Product	Weight(%)	Cu(%)	Recovery (%)
Copper concentrate	2.6	18.0	61.6
Copper-cleaned tail	12.2	0.72	11.7
Tailing of Copper	39.0	0.19	9.4
Graphite concentrate	0.4	0.6	0.3
Graphite-cleaned tail	20.4	1.8	5.6
Tailings of graphite	43.4	0.2	11.4

Head Grade : 0.76% Cu

(2) KESARPUR COPPER DEPOSIT

The villages Kesarpur, Dudhiasol and Madansahi encompassing the copper ore deposit are located between latitudes 22°04' & 22°07' and longitudes 86°40' & 86°42'. The nearest railhead is Baramera R/s on Baripada-Bangriposi narrow gauge track. N.H.5 passes through Baramera, 5 km away from the Kesarpur copper sulphide deposit.

Geological Set-up

With the South Singhbhum Copper thrust entering into Orissa at east, with a south easterly swing, Kesarpur-Kusumbari areas have developed sheared metabasites, within the Iron Ore Super Group greenstones and are pock-marked on surface with old workings and waste dumps beside zones of visible malachitisation and azuritisation. Structurally, a major synform plunging north, wherein syntectonic granite is placed at core ; the limbs and the core are uniformly affected by the shear, 20 to 40m wide. Surficial show of primary chalcopyrite is often selective to the contact of the granite and the metabasics, both of which are transversed by the shear.

The locii of mineralisation is essentially structural though fissility and porosity of selected lithotypes like metabasic rocks have facilitated better entrapment of sulphides to form lode deposits.

Details of Deposits

Copper sulphides as stringers, veins, lenses and disseminations have been concentrated as peak and lean zones; the peaks making lenticular ore bodies. The chief minerals are pyrite, pyrrhotite and chalcopyrite, with minor amounts of nickel and molybdenum, whose mineral phases are inferentially drawn to be millerite pentlandite for Ni and molybdenite for Mo. 100 to 4,000ppm Ni was reported from Dudhiasol West. Mo reported at >5 to <40ppm in most spots. Other metallic associations include Zn <200ppm, Pb 10-20ppm, Co 20-120ppm, Ag <1 ppm, As <1,000ppm, Cd <100ppm, Zr 15-800ppm, Sn <10-10ppm, Ga 5-20ppm, Ba 100-1,500ppm, Sr 60-1,000ppm and Se <20ppm, 4 discontinuous lodes varying in strike lengths from 64m to 1,002m and thickness from 1m to 10.07m have been delineated.

Exploration Inputs

24 boreholes totalling 3,405.95m of drilling had been undertaken in Kesarpur East Block in a 3-level intersection sequence; the 1st level at 30m, the 2nd at 70m and the 3rd at 100m below surface respectively; at interval of around 100m and establishing a strike length of 1,200m for the ore.

Peneplained surface level on the lode system having attained 110m over the M.S.L. the R.L. of the 1st level of intersection is 80m, same of the 2nd level 40m and the 3rd at MSL - 10m.

Ore Reserves

On the basis of 0.8%Cu as cut-off grade and 1m as the minimum stoping width for the estimations; 4 small narrow & discontinuous lodes with average grade ranging from 0.89% to 2.09% Cu have been defined between the sea level and 110m R.L.

The overlying 'Oxidised Zone', of about 10m thickness has not been taken into account for reserve estimation. For computation of reserve, 2 cut-off grades of 0.4%Cu and 0.8% Cu have been taken into account. For categorisation of ore reserves, the limits of ore intersected by drilling and falling within the cut-off grades have been classed as "Probable" reserves. Only the likely geological extensions inferred within limited distances beyond these stipulated boundaries, have been classed as "Possible" reserves. They are, as under (with reserves and grade at 0.8%Cu cut-off duly supplemented by additional resource at 0.4% Cu cut-off computed to serve as an index of the resource base for a long term perspective.)

Name of Block	**Probable Reserve & Grade**		**Possible Reserve & Grade**	
	0.8% Cu C/O	**0.4%Cu C/O (Addl)**	**0.8%Cu C/O**	**0.4%Cu C/O (Addl)**
Kesarpur (East)	1.16Mt : 1.59%	x	0.50Mt : 1.59%	x
Kesarpur (West)	0.11 : 1.49%	0.21Mt : 0.57%	0.05 : 1.20%	0.11 : 0.61%
Madansahi	0.08 : 1.30%	0.23 : 0.53%	0.09 : 1.33%	0.37 : 0.52%

Grand Total of Probable & Possible Reserves at 0.8%Cu Cut-off Grade (Economic)
= 2.16 million tonnes :
with 1.54%Cu average

Additionally,
Grand Total of Probable & Possible Reserves at 0.4%Cu cut-off Grade
= 1.27 million tonnes :
with 0.55%Cu average

Exploratory Mining

Drilling and exploratory mining undertaken by the Mineral Exploration Corporation Limited in Kesarpur (East) block revealed the following features

Level	Cross-cut off.	Ore Width	Grade Cu%
1st	Inclined shaft	52.80m	0.91
	Vertical shaft	33.35	1.02
2nd	Inclined shaft	52.65	0.33
	Vertical shaft	34.75	1.02

The results indicated the predominance of shoot pattern of mineralisation and the inherent erraticity in the disposition of the shoots, which hardly could be followed up in underground mining. Open-cast operations within limited strike lengths could be cost-effective.

(3) SARGIPALI LEAD ORE DEPOSIT

Sargipali galena deposit (22°03' : 83°35') lies between the villages Lokdega (22°02' : 83°55') and Bharatpur (22°03' : 83°56') in Sundargarh district . Jharsuguda Junction of the South Eastern Railway, 45 km away, is the nearest major railhead.

Geological Set-up and Mineralogy

Located within the structural frame of the Gangpurs, the country rocks comprise dolomite, quartzite, garnetiferous mica schist striking WNW-ESE, with dips of 35° - 45° due SSW. Local structural geology comprises F_1 (tightly appressed & recumbent folds due E-W) and F_2 (broad and open folds over limbs of earlier folds trending WNW-ESE and with well-developed axial plane schistosity). Granite and pegmatite occur as intrusives. The sulphide mineralisation is confined to the grey coloured garnetiferous biotite schist.

The area has undergone two main phases of folding resulting in a easterly plunging isoclinal anticline. The southern limb of this plunging anticline is mineralised.

The common primary minerals of the deposit are galena, chalcopyrite and sphalerite, The secondary ore minerals occurring in the oxidised area are cerussite, azurite, malachite, covellite etc. Other sulphide minerals present are pyrite, pyrrhotite and arsenopyrite. No mineral of silver has been identified. Silver may be occurring in the crystal lattices of galena. No typical gossan has been recorded.

Exploration and Reserve

Systematic exploration involving drilling has been carried by G.S.I. during 1966-72 and since 1974 by Hindustan Zinc Limited. HZL carried out exploratory mining in the form of 2 inclines. In order to delineate the ore body at different levels, underground horizontal and inclined diamond core drilling were done by HZL.

The cumulative strike length of Sargipali deposit is 1,525 m, the western sector 715 m and the eastern sector 810m. Reappraisal of the exploration data in the project stage estimated the in-situ demonstrated ore reserve of 2.06 million tonnes between 220 and 60 mRL with 6.73% Pb, 0.33% Cu and 51 ppm of Ag at 3% cut-off.

Mining

Hindustan Zinc Limited hold a mining lease of Sargipali deposit covering an area of 499.59 hectares. Mining commenced in 1980 and the development includes two incline shafts. The maximum depth attained so far is 180m. At present, the ROM production is 8,000 t/month, which yields about 650 tonnes of Pb concentrates. The concentrates are smelted in HZL's smelter at Vizag and Chandria (Rajasthan).

At the current level of production, the mine is expected to last for another 10 years.

CONCLUDING REMARKS

So far as the copper deposit in Adash is concerned, it nullifies the concept of the Eastern Ghat Granulitic Mobile Belt being barren of sulphide mineralisation. Mining of copper ore on a small scale along with graphite may work out to be viable.

Kesarpur copper deposit, because of its locational advantage, can be developed into a small mine. It is understood that a project is under consideration by Orissa Mining Corporation.

The life of Sargipali mine will depend on discovery of additional reserves. One possibility is sulphide mineralisation below the pegmatite intrusive at depth.

The High Resolution Aeromagnetic survey now in operation in the State may possibly throw up potential blocks for base metal ore mineralisation.

Bauxite

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1. INTRODUCTION

Bauxite is a heterogeneous ore composed chiefly of the aluminous oxide minerals gibbsite ($Al_2O_3 . 3H_2O$), the trihydrate and boehmite and diaspore ($Al_2O_3 . H_2O$), the monohydrates. Major impurities in bauxite ores include iron oxides, silica, aluminium silicates and titanium oxides. Free moisture in crude bauxite, as mined, may range from 5 to 30 %.

Although bauxite is the main source of aluminium, the second most abundant metal element in the earth's crust after silicon, other aluminium resources for the future include kaolinitic clays, nepheline syenite, anorthosite and alunite.

Bauxite is mined mainly for production of alumina by the Bayer's process, which has remained practically unchanged since its discovery in 1888.

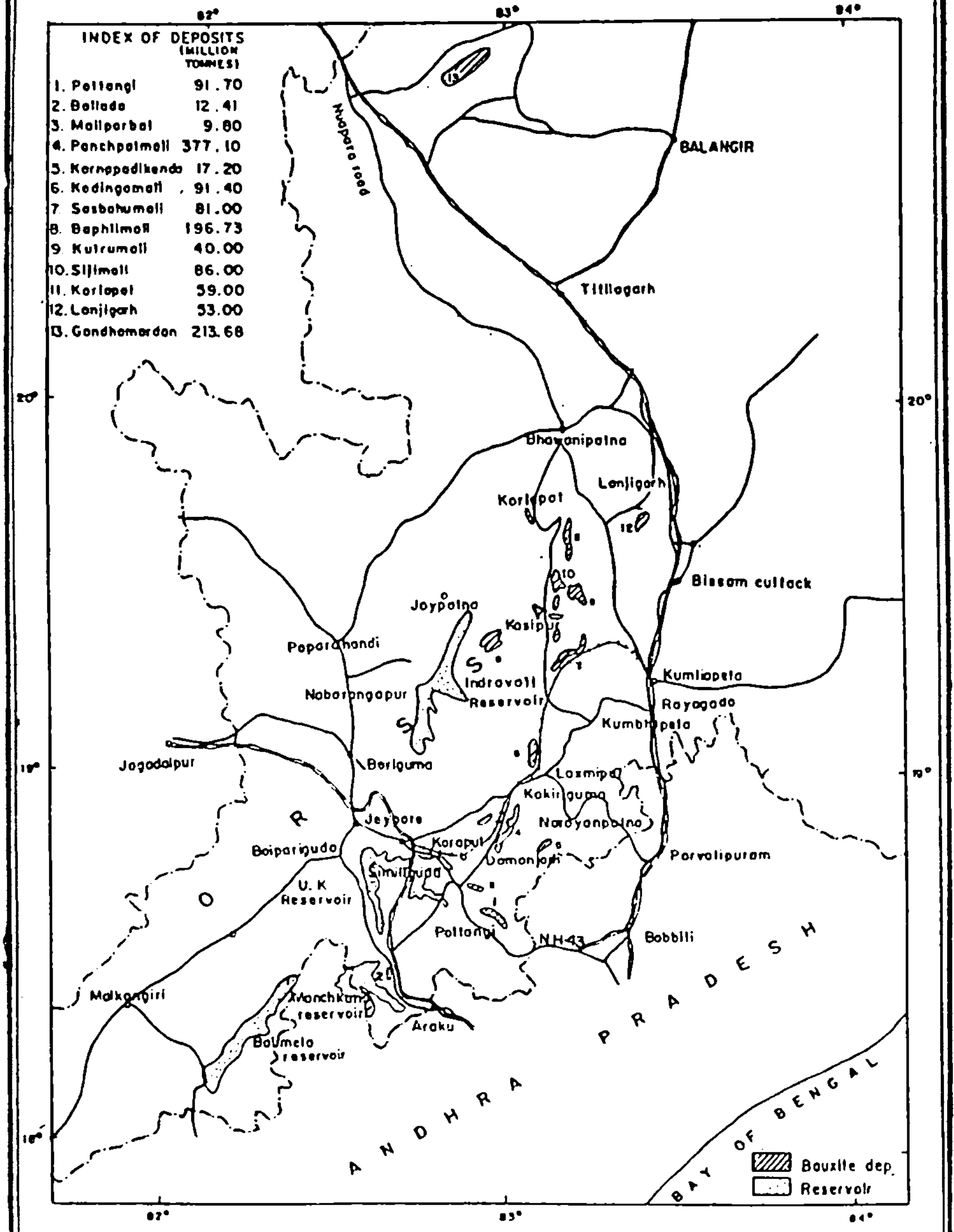
Bauxite, alumina and aluminium metal have considerable importance for India where the inventory of bauxite resources registered a seven fold increase from a level of 425 million tonnes during 1976 to over 2,900 million tonnes during 1981.

2. GEOLOGY

Bauxite deposits of Orissa are of diverse parentage. The important deposits are associated with the Eastern Ghat Super Group of rocks and form the major component of the East Coast Bauxite (ECB) deposits. The deposits are of lateritic type and owe their origin to in situ chemical weathering of khondalites and charnockites, and more specifically khondalites, the garnet-sillimanite-graphite gneisses and schists and their variants.

The other deposits, smaller in dimensions are residual products of lateritisation of metavolcanics as in Dholkata pahar of Keonjhar district and Simlipal complex ; shales of BIF as in Kusumdih of Sundargarh district and Vindhyan sediments in Khariar highlands of Kalahandi district.

FIG. I EAST COAST BAUXITE DEPOSITS
ORISSA SECTOR



2.1 Eastern Ghat Super Group

The major bauxite deposits of Orissa occur as a very gently undulating blanket capping the parent rocks on plateau tops in this unique bauxite province and constitute an integral part of the lateritic profile, at elevations of 900 m to 1400 m above MSL. Steep or vertical scarp faces along the periphery of the laterite bauxite caps, barren to sparse vegetation at the hill tops, fairly dense growth of flora along the slopes of the plateaus characterise the ECB deposits (Fig. 1).

Bauxitisation is more pronounced in the case of khondalites. A generalised profile of the ECB deposits is as follows :

Soil
Laterite
Aluminous laterite/bauxite
Lithomarge/kaolinite
Partially altered khondalite
Unaltered khondalite.

2.2 Simlipal Group

The Simlipal assemblage of rocks are equivalent of Dhanjori group and lie above the eroded surface of BIF bearing Gorumahisani group and Singhbhum granite. These rocks include ultramafics, alternating layers of metavolcanics and sedimentary quartzites, gabbro-anorthosite suite, granitic suite intruded by the Amjori sill belonging to Newer dolerite suite. Both ultramafics and metavolcanics are lateritised giving rise to nickeliferrous laterite and aluminous laterite respectively.

The Dholkata Pahar around Kuanr lying to the west of main Singhbhum granite body are underlain by volcano-sedimentary assemblages similar to those of the Simlipal plateau. It is bauxitised and lateritised. A typical vertical profile of Dholkata Pahar is as follows :

Lateritic soil
Bauxite and laterite
Lithomargic clay
Metavolcanics

2.3 Noamundi Group (BIF)

The Noamundi group rocks are made up of a lower formation of manganiferrous shale, shale, phyllite and tuff, a middle formation of banded iron silica rocks and upper formation of phyllite, shale and tuff. Iron formations are extensively lateritised. In small exposures around Kusumdih, the shales are bauxitised and lateritised. The trap rock is conspicuously absent in this region. Besides, gradation of bauxite-bearing laterite into underlying rocks is not observed.

2.4 Purana Group

Unconformably overlying the rocks of the Eastern Ghat Group, there is a less deformed and less metamorphosed rock sequence with characteristic argillaceous, arenaceous and calcareous members of the 'Platform facies'. These rocks are considered to represent the Vindhyans. The boundaries of these rocks with the other rock units of the area are usually marked by highly feldspathic arkose and chert. The rocks comprise sub-arkosic quartzite, purple shale and upper quartzite. These occur as detached and discontinuous outcrops. They are exposed between Ampani and the Khariar highland almost following the M.P. boundary. Bauxite occurs as blankets and lenses on the Vindhyan shales of the Khariar high land. The bauxite is localised along a narrow east-west trending fault zone in the quartzite and is apparently derived from the topmost shale overlying the quartzite.

3. MINERALOGY

Mineralogical study carried out by X-ray diffraction, thermal analysis, electron microscopy and heavy mineral analysis of bauxites derived from different parent rocks reveal gibbsite as the main aluminous mineral. Other associated minerals include hematite, goethite, kaolinite, anatase etc. and are summarised as under.

i. Bauxite derived from khondalite consists of gibbsite, goethite and kaolinite in varying proportions with some hematite, ilmenite, garnet and sillimanite as accessory minerals. Dense gibbsite is in greater proportion in the bauxite overlying the charnockite whereas crystalline and cryptocrystalline gibbsite is common in the khondalitic bauxite. Bauxite derived from khondalite also exhibits botryoidal form and highly porous in nature. Gibbsite is pseudomorphous after sillimanite, garnet and feldspar which are the main constituents in a garnet sillimanite-quartz-feldspar gneiss (khondalite). In respect of bauxite derived from charnockitic rocks, it is mainly the feldspar that gives rise to gibbsite.

ii. Bauxite derived from metavolcanics contains gibbsite, boehmite, diaspore and small quantity of goethite. Ilmenite and rutile are present in small quantity. Presence of boehmite and diaspore suggest better grade bauxite formation. Two types of textures such as loose framework and tight collomorphous are the significant characters of Kuanr bauxite. Minute crystallites of boehmite and well defined crystals of gibbsite were noticed under SEM.

iii. Bauxite derived from shale consists predominantly of gibbsite and goethite with some hematite, diaspore, boehmite, anatase, magnetite, ilmenite and little kaolinite and quartz. The cryptocrystalline kaolinite forming pseudomorphs after ferromagnesian minerals are noticed at some places. Petrographic examination shows a variety of textural features, viz., collomorphous, vesicular and concretionary.

4. GEOCHEMISTRY

The major oxides which are of consequence in bauxite formation are SiO_2, Al_2O_3 & Fe_2O_3. The depletion of silica and enrichment of sesquioxide (Al_2O_3 +Fe_2O_3) are significant features in respect of different zones of the bauxite/laterite profiles derived from various parent rocks. Proportional enrichment of Al_2O_3 and Fe_2O_3 depends upon the availability of Al and Fe respectively in the parent rock and pH and E_h conditions prevailing during weathering process.

Thus, depending on the chemical behaviour of the major elements, the parent rock- bauxite/laterite profiles are divisible into the following four zones arranged from top to bottom:

Zone IV	Laterite zone
Zone III	Bauxite zone
Zone II	Lithomarge/Kaolinite zone
Zone I	Parent rock

The transitional relations of these materials with the overlying bauxite is clearly visible in some cappings but in some others it is absent.

In the zone of bauxite, the leaching of Si and Fe is enhanced with consequent enrichment of Al and Ti. But this trend of enrichment of Al and impoverishment of Fe and Si becomes reversed in the laterite zone. Practically, all the elements show a sharp change in this zone from the underlying bauxite zone. Fe and Si increases in their contents, while Al and Ti record a sudden decrease. The behaviour of LOI remains symphathetic with Al. The Ti values are slightly higher in the bauxites derived from charnockitic rocks than those from khondalite. The TiO_2 values are in general between 3% and 5% while the exceptions are 2% and 7% on the minima and maxima sides.

Some bauxites show enrichment of Ga and V upto a maximum of 100 ppm and 400 ppm respectively. Zr & Mn contents go upto 1000 and 400 ppm respectively. Rare earths, Ce and Th shows values upto 500 ppm. The trace element enrichment in the residuum is however, not systematic and progressive from the bed rock upwards. Possibly such of the horizons which consists of the resistant minerals that house these trace elements, when transformed in situ, result in their residual enrichment. It would appear that the relative enrichment of some of the trace elements is a direct function of the chemical composition of the parent rock.

Some of the important conclusion of Norton (1973) which are deemed helpful in defining the physico-chemical conditions likely to be prevalent during the formation of the bauxite and laterite are stated below :

1. Under a wide range of E_h and pH conditions, both Al and Fe have very low mobilities and the soil type will reflect the Al/Fe ratio of the protore.

2. Under conditions of low pH and high E_h, lateritisation occurs if Fe is available in the protore.

3. Under conditions of low to intermediate pH and low E_h bauxitisation occurs if Al is available in the protore.

5. GENESIS

It has not yet been possible to work out the exact mechanism of bauxite forming process because of the fact that 'Bauxite' is a weathered product developed due to the regrouping of the minerals of parent rocks containing Al and Fe and chemically unstable in the thermodynamic conditions and also due to the fact that any attempt to simulate the natural phenomenon of rock weathering in the laboratory proved futile.

Nevertheless, it is firmly believed that bauxitisation is a process of chemical weathering involving breaking down of silicate minerals of the parent rocks to form clays at the first stage. In the second stage, alkalies, alkaline earths and silica are leached with complementary enrichment of alumina, iron and some of minor and trace elements. This type of weathering is faster in tropical and sub-tropical environment where the temperature and seasonal rainfall are the highest giving rise to alternate wet and dry conditions. During wet periods, the soluble minerals are eliminated whereas during the dry season iron and aluminium are precipitated as oxides/hydroxides which finally hardens up by dehydration resulting in formation of 'bauxite/laterite'. The factors responsible to bring about the changes include (i) availability of a rock of suitable composition (ii) role of circulating water, (iii) role of hydrogen-ion concentration (p_H) and redox potential (E_h), (iv) engineering property of parent rock, (v) climate, (vi) topography, (vii) vegetation / organism and (viii) time.

Rocks belonging to all the three main classes i.e. igneous, sedimentary and metamorphic participate in the process of bauxitisation. Both field and laboratory investigations carried out by the author lead to the conclusion that the bauxite of Orissa are developed over charnockite, khondalite and metavolcanics through an intermediate lithomarge/kaolinite zone showing a profile development from parent rock to the bauxite/laterite. In the case of shales, the line of division between the bauxite/laterite and the underlying altered zone is well defined and clear cut.

On decomposition or chemical weathering of parent rocks, silicate minerals break-down resulting in kaolinisation of the rock in general and clay concentration of the original feldspar-rich portions in particular. The decomposition agents are either physical or chemical. The chief physical agents are changes of temperature and crystallizing salts. They only breakdown the rock into small fragments which are more likely to succumb to chemical reactions. Chemical decomposition is caused by the action of surface and ground water and the solids and gases dissolved therein. The presence of water is the basic requirement of all chemical weathering. Biological activity aids the process of bauxitisation/ lateritisation. Alkalies, bases and silica are leached from the clayey materials i.e. lithomarge/kaolinite as the case may be, with complementary enrichment of Al & Fe as oxides/ hydroxides resulting in formation of bauxite/laterite.

Silica shows a covariant relation with sesquioxide, i.e it decreases with increase in sesquioxide and vice versa. At a later stage Fe goes into solution alongwith some silica and Al is enriched resulting in the formation of bauxite. Subsequently, Al goes into solution with enrichment of Fe in the upper layer of the profile possibly as a result of capillary pressures and surface tension and / or meteoric water. These differential concentration of residual elements occurred in the profile with variations in degree of leaching and solution with depth. This variation is reflected in the formation of distinct lithological units, represented from base upwards, by lithomargic clay, lower laterite, bauxite and upper laterite, with characteristic mineral assemblage in each unit. Even laterite and bauxite are developed concurrently. The development of bauxite in restricted zones within the laterite profile under similar conditions of weathering of parent rocks is attributed to favourable drainage conditions due to the physical variations in the parent rocks which bring about changes in the hydrological properties i.e. higher permeability, a factor conducive to thorough leaching and removal of some chemical constituents leading to enrichment of alumina.

The bauxites of Kusumdih are derived from ferruginous shales and occur intercalated with laterites. The presence of fragments of shale in laterite suggests the origin of bauxite as due to the lateritisation of shales. Gradation of bauxite bearing laterite into underlying rocks is absent.

Under similar geologic and meteorologic environment it is perhaps the geomorphic expression that determines the mode of leaching and thus the nature of the end product (Ramam and Vaidyanadhan, 1979). It has been observed that the rate of precipitations is more and the actual evapotranspiration less in the high platforms. The potential evapotranspiration itself is less in the high platform than in the low land-forms and coastal plains. This clearly manifests the interrelationship between altitude, rainfall and evapotranspiration. Laterites occur at every level from coastal plains to heights of +1400 aMSL but bauxite is confined to heights above 900 aMSL. However, in all the places, the bauxites /laterites are developed on relatively broad based and moderate to gently sloping landforms. It is seen that high level khondalite, charnockite and metavolcanics are bauxitised and lateritised whereas at low level these rocks are only lateritised. This may be attributed to geomorphic expression for better drainage, more time duration and the environmental factors favouring bauxitisation at high levels.

Further, bauxites/laterites over khondalites, charnockites and metavolcanics show the gradual downward passage into lithomarge/kaolinite and weathered rocks below and the presence of relict structural elements of the parent rocks bear evidence to the in situ nature of the residual profiles. These bauxites/laterites are grouped under 'residual type'.

It is evident that the parent rock, the topographic level, plateau formation and age of rocks have strong influence on bauxitisation. Since it is a weathered product its formation is positively influenced by other environmental factors such as pH, E_h, drainage and engineering properties e.g. permeability, porosity, grain size, crystallinity etc. of the mother rock mass.

6. AGE

Being a weathered product, evaluation of the age of the bauxite can be attempted on the basis of the palaeoclimate, since wet tropical climate is recognised to be a major critical factor in the formation of bauxite.

Bardossy(1973), who analysed the trend of bauxite formation on a global scale from the plate tectonics angle suggested that formation of lateritic bauxite in the Indian and African plates could have commenced in Upper Cretaceous and continued in Tertiary.

Palaeomagnetic reconstructions of the latitudinal position of India during different periods reveal that the peninsular India landmass was within the tropical belt during Cambrian and Ordovician times and again between the Paleocene and Recent times (Banerji, 1990).

It is difficult to prove the existence of bauxite/laterite of Ordovician and Cambrian times. All known occurrences are believed to have been formed during the last 65 million years i.e. Upper Cretaceous to Pleistocene.

7. OCCURRENCES

In Orissa, major portion of the land mass is underlain by Precambrian rocks, the oldest rocks in the earth's crust. The remaining area is made up of rocks belonging to Gondwana, Tertiary and Quaternary times.

Geology and geomorphology of Orissa reveal that certain rock types at certain topographic levels have been bauxitised and/or lateritised while other lithounits are not bauxitised/lateritised at all. It is evident that bauxitisation/lateritisation not only depend upon lithology but also on topography and environment of a particular region.

All the East Coast Bauxite cappings over khondalite in Orissa sector e.g. Ballada, Maliparbat, Pottangi, Panchpatmali, Kodingamali, Karnapadikonda, Baphlimali, Sijimali, Lanjigarh etc. occur on a single planation surface (+900 aMSL) despite a marked altitudinal difference amongst them. Some cappings like Panchpatmali and Baphlimali have vast areal spreads from 10 to 15 sq. kms. and some are small less than 1 sq.km. (Maliparbat). These plateaus are scattered over an area of 4,000 sq. kms.

Bauxite cap the Gandharmardan Plateau (940-1000 aMSL) over khondalite on the border of Bolangir-Sambalpur districts in NE-SW direction over a length of about 9.8 kms.

Bauxite occurs in the Khondmal hills overlying the Vindhyan shale at an elevation of 960 aMSL and in the Barepat Dongar, Sandbahal and Sainipara hills of the Khariar highland.

Small and isolated aluminous (bauxite) cappings occur over BIF (shale) formation at elevations from 610 to 671 aMSL around Kusumdih in Sundargarh district.

Bauxite with intercalated laterite cap over metavolcanics on the flat topped hill of Dholkata Pahar, near Kuanr with several narrow tongue like projections (Kanjipani range) west of Keonjhargarh. The tops of hill range vary from 727 to 848 aMSL with intervening valleys around 600 aMSL.

In Simlipal complex (Mayurbhanj), laterites are observed around 1000 aMSL. The spongy aluminous laterite/bauxite occurs as sheets and boulders occupying the flat topped hills made up of metavolcanics i.e. all the hill ranges west of Nawana and east of Simlipalgarh, Bakua etc.

8. EXPLORATION

The earlier efforts for exploration of the bauxite deposits in the State by the Directorate of Mining & Geology and the Geological Survey of India comprised geological mapping, channel sampling of the scarp faces, limited pitting and wet drilling.

During 1976-80, a crash programme of detailed evaluation of the bauxite prospects, known as East Coast Bauxite Project was implemented jointly by the Directorate of Mining & Geology, Geological Survey of India and the Mineral Exploration Corporation Limited. The objective of the ECB project was to establish sufficient reserves of bauxite for meeting the indigenous requirements and supporting two alumina plants of 6,00,000 to 8,00,000 tonnes/year capacity.

The evaluation of the deposits was made at a cut-off grade of +40% Al_2O_3 and -5% SiO_2. The exploration methods adopted in ECB project include

i. Topographic surveying
ii. Geological mapping (1:10,000, 1:2,000 & 1:1,000)
iii. Exploratory mining (shallow & deep pits, trenches, adit).
iv. Drilling (dry method) at 200mX200m, 100mX100m & 100mX50m grids.
v. Metre-wise sampling of drill cuttings and exploratory openings.
vi. Bulk sampling
vii. Integrated laboratory investigations
viii. Geostatistical evaluation

The ECB project is unparallel in the magnitude of inputs in terms of manpower, machineries and resources. Though a critical review of the exploration data is beyond the scope of the paper, it would be relevant to report the following important findings.

a. For establishing different categories of reserves, drilling at the following grid intervals was considered adequate besides limited pitting, necessary chemical and mineralogical studies.

"A" Category reserves	100mX100m or 100mX50m
"B"	100mX100m or 100mX200m
"C"	200mX200m

b. Alumina content of bauxite estimated by vacuum drilling is lower than that by drilling in Panchpatmali deposit. Silica contents do not show any significant variation.

c. The thickness of overburden and ore zones show wide variations, the roof and floor of the ore zone are wavy, the latter arising due to differential leaching of the parent rocks. These features have necessitated confirmatory pits and close interval (25m X 25m) drilling in some test cases.

d. Study of geomorphological features reveals that cappings with surface slopes of 1 in 7 to 15 overlie thicker and higher grade bauxite zone and abrupt change from gentle to steep surface slopes indicate the boundary between bauxite/laterite and altered parent rock.

9. ORE CHARACTERISTICS

The bauxite are very hard and massive in the top and moderately hard and spongy below. The pale buff to creamy white coloured bauxite is mostly of high grade and is recorded mostly on the surface. Bauxite, pale pink in colour and with a clayey appearance, has been found to occur towards the lower part of the bauxite zone. Crystalline, cryptocrystalline and dense gibbsite occur in varying proportions. The porosity and moisture contents are highly variable. Specific gravity ranges between 2.1 and 2.5.

Bauxite derived from khondalite retain the continuity of the structural features like foliation and schistosity of the bedrock whereas those from the charnockite are massive with irregular surfaces and relatively dull earthy look. Further, there is a distinct morphological contrast between the two types. The bauxite overlying charnockite are relatively flat whereas those on the khondalite are highly jointed with several sets of intersecting joints often resulting in filling of lateritic materials. Bauxites over khondalites and charnockites exhibit massive to spongy and vermicular textures. Outlines of relict sillimanite and garnet are discernible even to the naked eye in bauxites derived from the khondalitic gneisses.

Bauxite derived from shale show crude sub-horizontal stratification produced by the alternate layering of the ferruginous and aluminous minerals probably due to compaction of the weathered mass. The bauxite zone also contains small lateritic patches and cavities filled with ferruginous materials.

Bauxites of different types like massive and disintegrated, spongy, cellular and oolitic are seen over metavolcanics. Those over Vindhyan shales are characterised by oolitic, pisolitic, concretionary, vesicular, vermicular, spongy and brecciated textures.

The ECB deposits range in thickness from 10 to 50 m, the overburden comprising soil and laterite is in general 1 to 2 m thick.

The suitability of bauxite for alumina production depends upon the mineralogical form, the quantity of reactive silica and extractability by the Bayer's process. The ECB deposits are predominantly gibbsitic (65-75% gibbsite) and about 90-95% of total alumina is extractable at low temperature and pressure thereby entailing lower consumption of caustic soda for digestion. The alumina contents vary from 45% to 48% and silica ranges from less than 2% to 3%. The other constituents of ECB deposits of Orissa include 20-25% hematite including goethite, 3-5% kaolin and 2-3% anatase including rutile. The ECB are vesicular, porous and friable.

10. RESERVES

The total reserves of bauxite in the world are estimated at 23.2 billion tonnes (1990). The Indian reserves are placed at 2,911 million tonnes. The total reserves in Orissa are estimated to be 1,670 million tonnes. The reserves and grades of some of the important deposits are indicated in the following table. As mentioned earlier, the estimate is based on +40% Al_2O_3 & -5% SiO_2 cut-off.

District	**Name of Deposit**	**Bauxite bearing area in sq. km.**	**Average thickness (In metres)**	**Reserves in million tonnes.**	**Average Grade**	
					% Al_2O_3	**%SiO_2**
KORAPUT	Panchpatmali	17.2	14.00	377	46.00	2.25
	Pottangi	4.5	10.40	92	44.10	1.40
	Balada (Padwa)	2.0	7.70	12	46.7	2.48
	Kodingamali	6.0	13.65	91	46.48	2.19
	Baphlimali	9.0	12.00	196	45.21	2.19
	Karnapodikonda	2.5	5.00	17	46.58	1.73
	Sasbohu-Pasangmali	9.0	9.20	81	41.10	2.63
KALAHANDI						
	Karlapat-Polingpadar	8.0	12.58	224	40.00	3.00
	Kutrumal-Tangridongar.	6.0	8.00	40	41.40	3.36
	Lanjigarh	6.0	9.50	73	46.07	3.36

District	Name of Deposit	Bauxite bearing area in sq. kms.	Average thickness (in metres)	Reserves in million tonnes.	Average Grade	
					% Al_2O_3	%SiO_2
KALAHANDI (Continued)	Sijimali-Kisanmali	9.0	11.00	224	43.17	1.65
	Taljhir-Gorokhpur Khondmal hills (Khariar highland)	0.6	3.00	2	40.00	3.12
BOLANGIR						
SAMBALPUR	Gandhamardan	12.5	14.00	213	46.00	2.25

Besides the deposits described above, there are a number of deposits in the districts of Koraput, Rayagada, Kalahandi, Phulbani, Keonjhar and Sundargarh which together add up substantially to the overall reserves of the state. A very significant feature of the deposits is their low silica content and consequently easy extractability of alumina by Bayer's process.

11. MINING

Following the proving of bauxite reserves in Panchpatmali, one of the largest single deposits in the world, National Aluminium Company Limited (NALCO), a company fully owned by Government of India has developed a mechanised opencast mine for an annual production of 2.4 million tonnes. The other units of the complex include establishment of an alumina plant of 8,00,000 tpa capacity, an aluminium smelter of 2,18,000 tpa capacity and captive power plant of 600 MW capacity. The complex envisages export of 3,75,000 tonnes of alumina per year. All the units became fully operational during 1988.

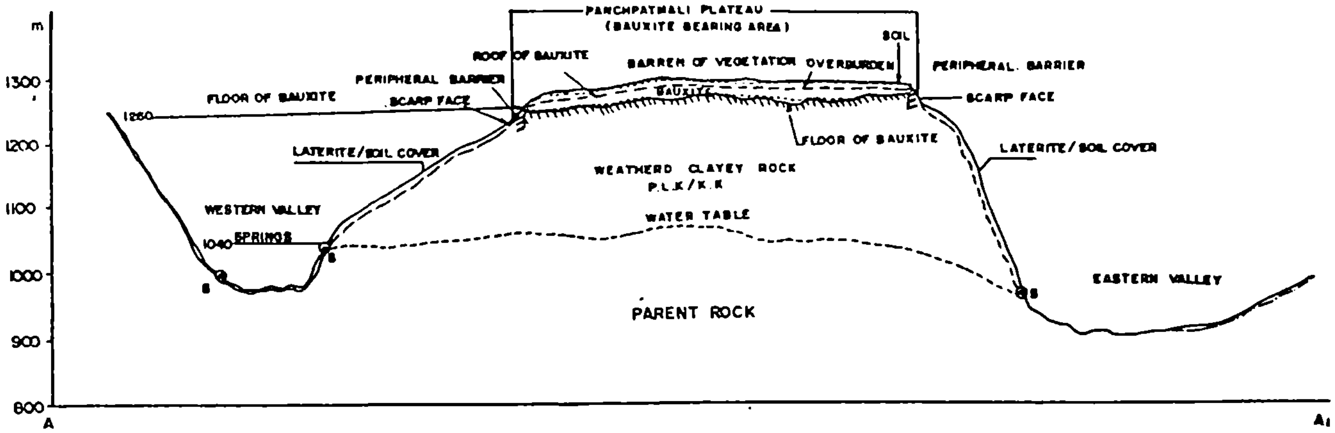
The process know-how and basic engineering for the mine, alumina and aluminium plants have been provided by Aluminium Pechiney of France.

NALCO holds a mining lease of Panchpatmali deposit covering an area of 7,204.74 hectares.

Considering the irregular roof and floor profile, development drilling at 25m x 25m grid using vacuum suction drill (Edson 2000) was undertaken and mining plan was prepared using computerised geostatistical technique and modelling.

A typical bauxite profile of Panchpatmali deposit (Fig. 2) is as follows :

FIG.2 VERTICAL SECTION ACROSS PANCHPATMALI HILL SHOWING THE BAUXITE DEPOSIT AND PERENNIAL HILL STREAMS



S- Source of Perennial Stream

Scale
Horizontal-1:10000
Vertical- 1:4000

Formation	Thickness	(Metres)
	Range	Average
Soil	0-3	
Laterite (Ferruginous and Siliceous)	0-8	2.5
---------- Roof of Bauxite horizon ----------		
Aluminous laterite/bauxite	0-35	14.5
---------- Floor of Bauxite ----------		
Transition zone	10-15	
Clay with partly lateritised/ kaolinised khondalite (PLK & KK)		
Parent rock (khondalite)		

The technique involves the following sequential operation .

i. Removal of top soil and lateritic overburden 6 months ahead of bauxite mining.

ii. Modified 'Trenching Method' consisting of development of roughly parallel trenches more than 40 m wide with staggered faces instead of the conventional 'benching method' to facilitate extraction of bauxite with irregular roof and floor and variable thickness,. Bauxite is extracted in two slices, the first 8-12 m thick by normal drilling (150mm dia) and blasting involving ANFO and the second selective extraction in 2-4 m thick slices by backtoe hydraulic excavators/ rippers.

iii. Maintenance of a 15m wide peripheral barrier for safety to prevent accumulation of rain water in the mines and environmental considerations.

iv. Loading and transportation of OB and ore by front end loaders-shovel -dumper combination and articulated dumpers.

v. Crushing of ore by double roll toothed crusher @ 900 tph from 800 mm feed size to -150 mm.

vi. Transportation of the crushed ore by a 14.63 km long downhill single flight curved cable belt conveyor system.

vii. Back filling of the mined out pits with fragmented OB removed earlier from the advancing OB faces and top soil and making them ready for plantation,.

viii. Implementation of appropriate environment protection measures in accordance with the EMP approved by the Ministry of Environment and Forests.

12. INDUSTRIAL USES AND SPECIFICATIONS

About 90% of bauxite produced in the world are consumed for production of alumina. The other applications are as refractories and abrasives where bauxite is used in calcined form. Minor quantities of bauxite are utilised in production of iron and steel, cement, ceramics, chemicals and ferro alloys. In Steel Industry, bauxite is used as a slag corrector in place of fluorspar. The specifications of bauxite for various uses, as prescribed by BIS are as follows :

(% by weight)

Metallurgical	Al_2O_3	40	(min)
	SiO_2	4	(max)
	$Fe_2O_3 + TiO_2$	30	(max)
	P_2O_5	0.2	(max)
	V_2O_5	: 0.2	(max)
	LOI at 1100°C	: 20	(min)
	The bauxite should be predominantly gibbsitic.		
Refractory	Al_2O_3	58	(min)
	Fe_2O_3	3	(max)
	TiO_2	3	(max)
	CaO	0.5-0.6	
	LOI	27-30	
Chemical	Al_2O_3	58	(min)
	SiO_2	3	(max)
	Fe_2O_3	2	(max)
	TiO_2	4	(max)
	P_2O_5	0.3	(max)
	CaO + MgO	2	(max)
	MnO	0.1	(max)
	LOI	: 32 (max)	
Abrasive *	Al_2O_3	83	(min)**
	SiO_2	6	(max)
	Fe_2O_3	8	(max)
	TiO_2	3-4.5	
	Alkalies	0.7	(max)
	CaO + MgO	0.6	(max)
	P_2O_5	0.5	(max)
	$MnO_2 + Cr_2O_3 + V_2O_5$	1	(max)

* U.S Specifications

** As Calcined.

Steel Industry uses bauxite containing 45-54% Al_2O_3 and less than 5% SiO_2.

13. CONCLUDING REMARKS

The per capita consumption of aluminium in the country being less than 1 kg as against 25 kg in the developed countries, there is scope for a much higher utilisation of the metal. Fortunately, Orissa is endowed with vast reserves of metallurgical grade bauxite and of particular significance are the low content of reactive silica and predominantly gibbsitic composition. With the expertise, experience and confidence gained in the field of evaluation, mining and grade control, the utilisable reserves in the State will most certainly go up.

NALCO has already initiated steps to double the capacity of Panchpatmali mine to 4.8 million tonnes per year. Two other alumina plants, each of 0.8 to 1.0 million tonnes per year capacity are planned to be set up in Orissa. These are :

1. INDAL - TATA sponsored plant based on Baphlimali deposit.
2. L&T sponsored plant based on Kutrumali and Sijimali deposits and

Assuming materialization of all the three projects, annual production of bauxite in the State will register almost 4 fold increase over the current level of 2.5 million tonnes. Consequently, the annual revenue from royalty alone will go upto about Rs. 320 million from the current level of Rs. 80 million.

Future exploration should be directed to locate and evaluate refractory, chemicals and abrasive grades of bauxite in the State.

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Beach Sand Minerals

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1. GENERAL

The term "Beach Sand Minerals" also called "Heavy Minerals" is usually associated with a group of industrial minerals comprising principally Ilmenite, Rutile, Zircon, Monazite, Garnet and Sillimanite. The minor constituents include Staurolite, Spinel, Sphene, Hypersthene and Magnetite. The major gangue mineral in the beach sand deposits is quartz. The specifications, physical properties and major applications of Beach Sand Minerals are described in the following table.

Table I.

Mineral	Chemical composition	Specific gravity	Major applications
Ilmenite	$FeO. TiO_2$	4.67	Manufacture of titanium dioxide, a white pigment. Also used for the production of synthetic rutile and Ferro-titanium alloys.
Rutile	TiO_2	4.1	Coating of welding electrodes, titanium dioxide pigment, production of titanium sponge and metal.
Zircon	$ZrO_2.SiO_2$	4.68	Foundries, ceramics and refractories; manufacture of Zirconium metals and chemicals.
Sillimanite	$Al_2O_3.SiO_2$	3.24	Manufacture of high temperature refractories.
Garnet	$3RO. R_2O_3$ 3 SiO_2	4.68	Manufacture of abrasives, for polishing glass/T.V. tubes, wood, for sand blasting and water filtration. Due to restriction in the use of quartz (silica sand) for sand blasting and on account of silicosis, use of garnet is on the increase.
Monazite	Phosphates of the Rare Earths with variable amounts of thorium.	5.10	Production of Rare Earth compounds, Thorium, Uranium and Helium.

2. GEOLOGY AND NATURE OF DEPOSITS

The river systems draining the extensively developed Eastern Ghat Super Group of rocks (khondalite. leptynite. charnockite. etc) and their other metamorphic associates like granulite, migmatite and gneisses and basic intrusives account for the coastal placer deposits. The placer minerals along with other detritals have been subjected to mechanical and chemical recycling. Tidal waves, littoral drift, fluctuation of the sea level and wind action have played their part in the concentration of heavy minerals. Both transgressive and regressive phases appear to have influenced the processes of transportation, sorting and deposition of the detrital grains. In addition to the meta-sedimentary rocks, some igneous source is also indicated due to presence of euhedral crystals of zircon in the sands. By far, khondalites constitute the principal source rock of the heavy minerals. The geomorphology of the Ganjam coast is characterised by two sub-parallel dune systems frontal and rear separated by intermediate low lying area. In the IREL leasehold, although the heavy minerals have been uniformly distributed with marginal variation in time and space, maximum concentration is observed within 2 metres from the surface. Concentration declines sharply (less than 5% HM) below the water table. The dunes range in thickness from 5m to 15m. Higher concentration is observed in the frontal dunes. Average thickness of HM of which assessment has been made is 5 metres.

3. EXPLORATION AND RESOURCES

The resources of beach sand minerals in India are confined to the States of Kerala. Tamilnadu, Orissa, Andhra Pradesh and Maharashtra. There are a few occurrences of heavy minerals in the inland areas of Bihar and West Bengal. The total heavy mineral resources in India are estimated to be as follows :

	(in million tonnes)
Ilmenite	146
Rutile	8
Zircon	12
Sillimanite (including kyanite and andalusite)	54
Garnet	46
Monazite	Not Reported.

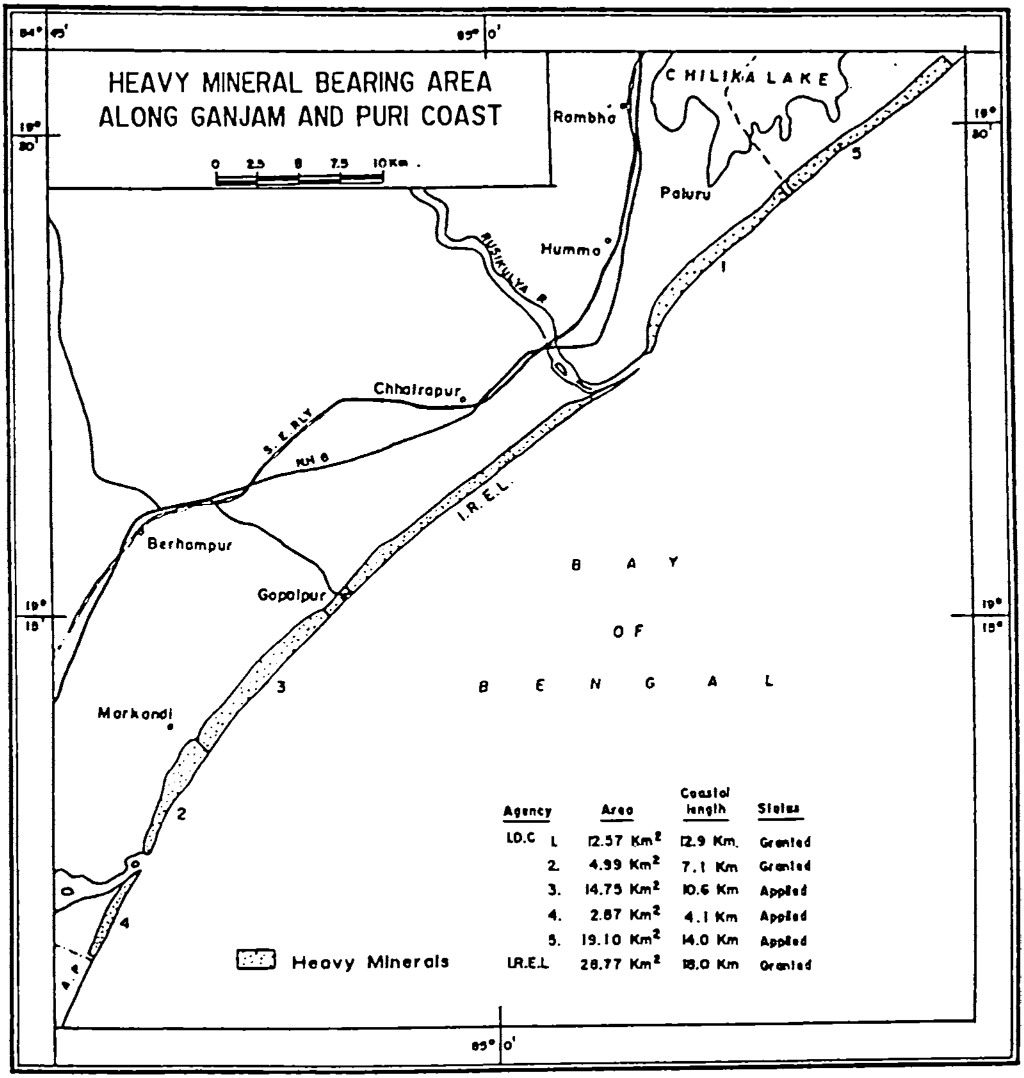
In Orissa, Atomic Minerals Division has explored a stretch of about 150 kms. from south of Mahanadi mouth to Orissa -Andhra Pradesh border and identified a number of potential deposits ranging in grade from 5% to 30% HM. Of this, the block held under lease by Indian Rare Earths Limited in Ganjam coast is most important from the point of view of reserve and grade. The IREL leasehold extends for a length of 18 kms. along Chhatrapur coast between Rusikulya river confluence in the NE and Gopalpur on the SW. The average width is 1.5 km. and the area is 27 sq. kms. Detailed proving by auger drilling has been carried out by the AMD at 45m-30m x 30m grid. A reserve of 230 million tonnes of mineral bearing sands has been estimated in the leasehold area, with an average grade of 20% HM. This is upto 1.5m below GWT. The mineral-wise break up of reserves of heavy minerals in the IREL leasehold has been estimated to be as follows :

Ilmenite	(9%)	20.7	million	tonnes
Garnet	(6%)	13.8	"	"
Sillimanite	(3%)	6.9	"	"
Rutile	(0.4%)	0.9	"	"
Zircon	(0.5%)	0.7	"	"
Monazite	(0.25%)	0.6	"	"
Others	(about 1%)	2.4	"	"

Systematic assessment of heavy minerals in beach sands of Ganjam coast (excluding the area covered under mining lease of IREL) has been carried out by the Directorate of Mining & Geology, Orissa during the field sesons, 1984-85 to 1990-91 by means of large scale geological mapping, contouring, drilling, sampling and laboratory investigations. The total coastal length and area covered under the assessment programme are respectively 19 kms and 14 sq.km. The grid density of auger drilling adopted is 150m (along the coast) x 30m (across).

Drilling has been done upto the water table and thereafter in the wet zone upto the base of the sand zone wherever feasible. Representative samples have been collected from the boreholes and bulk density determined. Volume of raw sands has been determined block wise. Different size fractions of heavy minerals have been determined and the heavy minerals have been separated by treating with bromoform. The heavy minerals thereafter are further separated into magnetic and non-magnetic fractions with the help of electro-magnetic separator. The percentages of different constituents of heavy minerals have been determined by grain counting under the microscope.

The summarised account of the reserves estimated for the different stretches of Ganjam coast explored so far by the Directorate of Mining and Geology is presented in the following table.



HEAVY MINERAL BEARING AREA ALONG GANJAM AND PURI COAST

Agency		Area	Coastal length	Status
I.O.C	1.	12.57 Km²	12.9 Km.	Granted
	2.	4.99 Km²	7.1 Km	Granted
	3.	14.75 Km²	10.6 Km	Applied
	4.	2.87 Km²	4.1 Km	Applied
	5.	19.10 Km²	14.0 Km	Applied
I.R.E.L.		28.77 Km²	18.0 Km	Granted

Block	Coastal Length(km)	Area (sq.km)	Reserves of HM (million tonnes)	HM (Expressed as % of Raw sand)
1. Pedalaxmipuram-Ramayapatna	7.50	5.00	1.22	8.62
2. Ramayapatna-Markandi	6.00	5.00	3.15	13.02
3. Niladripur-Kantiagarh	1.65	1.30	2.06	16.75
4. NE of Kantiagarh	1.20	1.10	1.87	15.05
5. East of Jhatiapadar	1.35	0.90	1.52	12.62
6. SE of Arunpur	1.35	0.85	1.20	11.74

The break-up of mineral-wise reserves is as follows

Reserves in '000 tonnes
Grade expressed as %

Minerals	Pedalaxmipuram-Markandi sector		Niladripur-Arunpur sector.	
	Reserve	Grade	Reserve	Grade
Ilmenite	1,864	4.86	2,449	5.20
Rutile	59	0.15	77	0.16
Leucoxene	19	0.05	45	0.09
Garnet	1,285	3.35	2,439	5.18
Sillimanite	941	2.45	1,520	3.23
Zircon	37	0.10	36	0.08
Monazite	45	0.12	18	0.04
Kyanite	12	0.03	14	0.03
Others	112	0.29	42	0.09
Total	**4,374**	**11.40**	**6,640**	**14.10**

(Grade is the percentage of individual heavy minerals in the raw sand)

A map showing HM bearing areas in Ganjam coast and the area held under ML by IREL is annexed.

4. MINING, PROCESSING AND PRODUCTION

Mining of raw sands is carried out by floating suction dredge followed by pre-concentration by a floating wet concentrator. Pre-concentration results in production of concentrates containing 90% HM. The concentrate thus produced is fed to a dry mill for separation of minerals. This is based on different physical properties, viz, electrical conductivity, magnetic susceptibility, specific gravity, size, surface property.

Orissa Sands Complex (OSCOM)

Orissa Sands Complex (OSCOM) of Indian Rare Earths Limited (A public sector undertaking of Government of India) was set up to produce 20,000 tonnes Ilmenite, 10,000 tonnes Rutile, 30,000 tonnes Sillimanite, 2,000 tonnes Zircon and 4.000 tonnes Monazite. The entire output of Ilmenite was to be processed to produce 96,000 tonnes of synthetic rutile. The synthetic rutile project based on leaching with HCl is not fully operational. The investment on the complex has touched Rs. 1,400 million.

Production of different heavy minerals in the OSCOM during the last 5 years are as follows :

(in tonnes)

Mineral	1989	1990	1991	1992	1993
Ilmenite	81,947	1,04,271	58,377	10,740	56,096
Rutile	1,928	2,811	1,607	180	1,572
Garnet	5	1			602
Sillimanite	1,625	1,172	606		1,014
Monazite	529	747	422	6	121
Zircon	814	1,350	970	85	754

5. EXPORT

Entire export of ilmenite is now handled by Gopalpur port. The ilmenite concentrates are transported by 100-200 tonne capacity manual and self-propelled barges for loading onto vessels of 10,000-20,000 DWT, berthed about 1.5 km away from the harbour. The current level of export is 71,000 tonnes (1993). The importing countries include Japan, Norway and Canada.

6. PROSPECTS

Steps are being taken to revamp the OSCOM with foreign collaboration. As a first step. reserves of HM below the GWT are being reassessed at a lower cut-off of 5% HM. For an unit like OSCOM with an investment of over Rs. 1400 million, an annual output of minimum 0.5 million tonnes of ilmenite is considered to be economic. The proposal under consideration includes production and export of ilmenite concentrates for production of pig iron by electrosmelting and recovering TiO_2 from the slag.

The I.D.C. of Orissa Limited is pursuing a proposal for production of ilmenite from the HM bearing sands north of IREL leasehold in Ganjam district.

The constituents of the heavy minerals are important input in refractory, ceramics and abrasive industries. There is good scope for promoting industries on small scale.

The other important development requirement is provision of facilities at Gopalpur port for berthing of vessels of minimum 25,000 DWT capacity.

China Clay

1. INTRODUCTION

Clay is a natural , earthy, fine grained hydrous silicate composed mainly of silica, alumina and water. Iron oxide, alkalies, titania, lime and magnesia constitute the gangue.

China clay is defined as a clay like material approximating the mineral Kaolinite (Al_2O_3, 2 SiO_2, $2H_2O$) where Al_2O_3, SiO_2 and H_2O are respectively 39.5%, 46.56% and 13.94%. It has a specific gravity of 2.6 and a fusion point of 1,785°C. Kaolinite is always fine-grained and normally occurs as crystals ranging in size from fraction of a micron upto several hundreds of microns.

It is a unique industrial mineral because it is chemically inert over a wide p_H range; white, has good covering or hiding power when used as a pigment or extender in coated films, soft and non-abrasive, has low conductivity of heat and electricity.

Although clays have been used for thousands of years, understanding of the molecular and atomic structure along with devices for measuring and observing their physical and chemical properties have only recently been made available and are continually being improved.

2. GEOLOGY AND OCCURRENCES

China clay is found to occur in a long belt stretching from southern Singhbhum to Mayurbhanj extending upto eastern Keonjhar in the Singhbhum Granite belt. Badampahar - Joshipur-Karanjia-Ramchandrapur belt with a number of deposits on either side of NH 6 is the most important china clay producing area of the State. There are a few other occurrences in Keonjhar, Sambalpur, Koraput, Sundargarh and Dhenkanal districts. Some of these have refractory properties. Kaolin occurs in form of pockets or lenses within the main mass of granite. The granite is rich in felspar and is medium to coarse grained. It is traversed by chlorite schists, epidiorites and pegmatites. Kaolin deposits have been formed by decomposition of felspathic granite. It is often noticed that better quality china clay deposits occur near the contact of granite with epidiorite or chlorite - schist. The china clay found in Joshipur area of Mayurbhanj district is pale cream to yellow in colour with moderate to good plasticity. The china clay deposits in Mayurbhanj district are believed to have been formed as in situ deposits by the alteration of felspathic granite.

The important deposits in Mayurbhanj district are found near Joshipur, Chanchbani, Dumuria, Jamda, Kadodiha, Jamkeswar and Thakurmunda. The thickness of clay zone varies from 10 to 20 meters. A typical mineralogical, chemical analysis of china clay of Joshipur area is as below :

Mineralogical Composition

Quartz	:	4-5%
Felspar	:	Less than 1%
Kaolinite	:	80 - 82%
Hydromica	:	10%
Limonite	:	1.5 - 2%
Other minerals		1-2%

Chemical Analysis (washed)

Al_2O_3	35.73 %
SiO_2	46.80 %
Fe_2O_3	1.49 %
TiO_2	0.62 %
LOI	12.60 %

The size analysis corresponds to a medium coarse grained variety, the particle size below 5 micron being 40%.

3. EXPLORATION AND RESERVE

Geological Survey of India carried out preliminary investigation of the china clay occurrences during the course of geological mapping during the 1960s. The Directorate of Mining & Geology implemented a programme of assessment of china clay resources in the Joshipur-Karanjia sector of Mayurbhanj district during 1979-82. Orissa Mining Corporation carried out detailed investigation in their Dumuria leasehold. The exploration inputs comprised large scale mapping, examination of the abandoned and existing quarries, pitting, drilling and sampling, followed by laboratory tests to ascertain the physical and chemical parameters, washability characteristics and recovery ratio. No specific pattern of pits and bore holes could be adopted on account of undulating and varying degree of weathering of the terrain, occurrence of intrusives like dolerite dykes etc. However, wherever possible, a grid pattern of 100m has been adopted. Many of the pits have been abandoned while in clay horizon on account of seepage of ground water.

The clay horizon is often admixed with lateritic soil, unkaolinised host rocks and mixed yellow clay. Therefore, while estimating "recoverable reserves", the in situ or "geological reserves" have been discounted by about 50%. The "recoverable reserves" for All India as on 1.4.90 are estimated at 986 million tonnes, while for Orissa, the figure is 157 million tonnes (Source : Indian Minerals Year Book, 1993). The break-up of recoverable reserves in Orissa is as under :

(in million tonnes)

	Proved	Probable	Possible	Total
State	0.20	59.70	97.50	157.40
Ceramic/Pottery :	0.03	0.09	0.20	0.30
Paper :	-	-	0.07	0.07
Rubber :	0.10	1.20	-	1.30
Unclassified/ Not known :	0.02	58.30	97.40	155.70

4. MINING, PRODUCTION AND PROCESSING

There were in all 16 leases for china clay in the State as on 1.4.94. Of these, 8 were in operation. The district-wise break-up of leases is as follows :

District	No. of leases	No. in operation
Bargad	5	2
Sambalpur	2	-
Mayurbanj	9	6

The State's production of china clay (washed) is around 11,000 tonnes, the mines in Mayurbhanj district contributing 10,000 tonnes. The major producing mines include those of M/s Jagdish Mines & Metals Pvt. Ltd. at Kadodiha with an annual production of 5,000 tonnes and of M/s Arun Udyog at Joshipur with a production of 3,000 tonnes of washed clay. The other important mine in this sector is at Chanchbani.

All the mines are opencast and shallow with a maximum depth range of 20 - 30 meters. The working is manual and in 1.5 m high benches. Clay is extracted below overburden comprising soil, alluvium, laterite, lateritic soil and mixed yellow clay of thickness varying from less than 3 m to 15m. The clay bed is over 5m thick. Mining operations are confined to about 8 months in a year. Mining operations remain suspended during the rainy season as the benches become weak and slushy and the quarries get waterlogged. Most of the benches have to be developed afresh at the end of the monsoon season every year. No blasting is involved. Mechanisation in the form of shovel for excavation and removal of overburden and rope haulage for hauling crude clay from the quarry bottom has been introduced in Kadodiha. Dumpers and tipper trucks are also used for haulage.

Almost the entire quantity of crude clay quarried is beneficiated to remove sand, silt and deleterious constituents like iron oxide, mica, tourmaline, titania. Processing of clay ranges from very simple and inexpensive washing and screening to very elaborate and expensive techniques involving crushing, blunging with dispersant, rough sedimentation, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, attrition, grinding, slurrying and delaminating.

The process steps in Orissa mines include washing, separation of sands by drain and drain sand catchers at - 150, -200 and -250 mesh wire nets and filter press to squeeze out water. The washed clay largely free from grit settle in tanks from where they are taken out, sun dried or dried on hot floor (coal fired) and bagged. On an overall basis, the washed clay of marketable grade constitutes around 40% of the crude, silica sand 45% and slime loss accounts for the balance 15%. However, these figures vary marginally from mine to mine. The washed product in 150-200 mesh range is utilised in rubber industry and constitutes about 5%. Products in 200-250 mesh size constitutes around 15%. These are suitable for ceramics. The - 250 mesh fraction constituting about 20% is suitable for use in the manufacture of paints, paper, textile, coating, soap and ultramarine blue.

Large heaps of silica are to be found in the china clay mines because of limited market outlet. The sands analyse 93 - 95% SiO_2 and less than 0.2% Fe_2O_3. These can, to some extent, be utilised in glass, ceramics, foundry, moulding industries with or without further processing. Washing can improve the silica content to about 97%, but the cost of washing does not encourage adoption of this practice.

5. USES AND SPECIFICATIONS

China clay has many industrial applications; as filler in paper, textiles, rubber, in the manufacture of potteries, ceramics, sanitary wares, glazed tiles, HT and LT insulations, white cement, insecticides, paints, cosmetics, refractory bricks, pharmaceuticals among others.

Although BIS has prescribed specifications of china clay for different industrial uses, the Expert Group constituted by the erstwhile Ministry of Steel & Mines has recommended the following specifications considering the trends by the user industries :

(A)	Ceramic	(1)	Water of plasticity	22.0%	
		(2)	Shrinkage after drying	8.0%	(Max.)
		(3)	Shrinkage after 1300°C firing (at Segar cone 12)	15.0%	(Max.)
		(4)	Colour after firing	Perfectly white	
		(5)	Grit	2.0%	(Max.)
		(6)	Fe_2O_3	1.5%	(Max.)
(B)	Textile & paper coating	(1)	Residue on 53 micron IS Sieve	0.1%	(Max.)
		(2)	Particles larger than 10 microns in diameter	5.0%	(Max.)
		(3)	Particles smaller than 2 microns in diameter	62.0%	(Max.)
		(4)	Relative density at 27/27°C	2.5 - 2.9%	
		(5)	Loss on drying	6.0%	(Max.)
		(6)	Loss on ignition	14.0%	(Max.)
		(7)	Matter soluble in HCl	2.5%	(Max.)
		(8)	Fe_2O_3	0.7%	(Max.)
		(9)	Colour reflectance to blue light of wave length 3040 A°	80 - 85%	
(C)	Rubber	(1)	Residue on 53 micron IS Sieve	1.0%	(Max.)
		(2)	Particles larger than 10 microns in diameter	7.0%	(Max.)
		(3)	Particles small than 2 microns in diameter	50.3%	(Min.)
		(4)	Loss on drying	2.0%	(Max.)
		(5)	Loss on ignition	14.0%	(Max.)
		(6)	Matter soluble in water	0.5%	(Max.)
		(7)	Matter soluble in HCl	2.5%	(Max.)
		(8)	CaO	0.007%	(Max.)
		(9)	Fe_2O_3	0.7%	(Max.)
		(10)	MnO	0.015	(Max.)
		(11)	Oil absorption	50 ml per 100 gm	(Min.)
		(12)	Copper	absent	

(D) Filler in paper	(1)	Residue on 53 micron IS sieve	1.0%	(Max.)
	(2)	Particles larger than 10 microns in diameter	20.0%	(Max.)
	(3)	Particles smaller than 2 microns in diameter	35.0%	(Max.)
	(4)	Loss on drying	6.0%	(Max.)
	(5)	Loss on ignition	14.0%	(Max.)
	(6)	Matter soluble in water	0.5%	(Max.)
	(7)	Matter soluble in HCl	2.5%	(Max.)
	(8)	Fe_2O_3	0.7%	(Max.)
	(9)	p_H value of aqueous extract	4.5 to 7.5%	
(E) Insecticide	(1)	Residue on 53 microns IS sieve	2.0%	(Max)
	(2)	Particles larger than 10 microns in diameter	20.0%	(Max)
	(3)	Particles smaller than 2 microns in diameter	35.0%	(Max.)
	(4)	Loss on drying	6.0%	(Max.)
	(5)	Loss on ignition	14.0%	(Max.)
	(6)	Matter soluble in HCl	2.5%	(Max.)
	(7)	As_2O_3	10 ppm	(Max.)
	(8)	Fe_2O_3	0.7%	(Max.)

6. GENERAL REMARKS

The china clay mining and processing industry of the State has not developed owing to a number of reasons. These are :

a. Seasonal working;
b. non-adoption of better processing techniques,
c. lack of direct marketing access to consumers,
d. competition from soapstone, pyrophyllite, which have emerged as alternative raw materials for the traditional china clay based industries, and
e. limited china clay consuming industries in the State.

There is greater demand for calcined clay as a substitute for titanium dioxide pigment in paper, paint and plastics. Future programme should seek a solution to the above deficiencies and take cognizance of the technological developments.

[The paper is based on information from unpublished investigation reports of the DMG and china clay producers].

Chromite and Nickel ore

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GENERAL

Both chromium and nickel are metals of strategic importance. These are indispensable for industrial complexes including aerospace, steel and special alloys. Manufacture of defence equipment, space and aviation vehicles etc. is largely dependent on these two metals and their products.

Chromite belongs to the spinel group and has the basic formula $R^{++} R_2^{+++} O_4$ where R^{++} = Mg, Fe with traces of Mn and Ni and R^{+++} = Cr, Al, Fe with traces of Ti and V. It has five major components viz, MgO, FeO, Cr_2O_3, Al_2O_3 and Fe_2O_3, whose proportions are greatly controlled by the composition of the magma from which the primary silicates and chrome spinel crystallized. Pure chromite contains 67.9% by weight of chromic oxide (Cr_2O_3) or 46.5% by weight of chromium.

Chromite is the only economic source of chromium and India has fairly large resources of this mineral mostly concentrated in the State of Orissa.

Nickel is obtained from the primary sulphide ores and secondary silicate/oxide ores associated with the ultramafics. India has no sulphidic nickel-ore, whereas the oxide ore i.e. lateritic nickel ore of considerable quantity has been located in the Sukinda sector.

Geology of the chrome and nickel ores of Orissa, status of exploration and mining, resources, specifications for utilisation in different industries, production, demand pattern and mineral dressing characteristics etc. have been described in the following paragraphs.

A. CHROMITE

1. Location and accessibility

Deposits of chromite in Boula-Nuasahi area of Kendujhar district was discovered in 1942 and mining started from 1943. The area around Nuasahi (21° 17' N: 86° 20' E) lies at the south eastern fringe of Boula state forest and is connected to S.E Railway and N.H.5 at Bhadrak town by an all weather 45 kilometers long metal road passing through

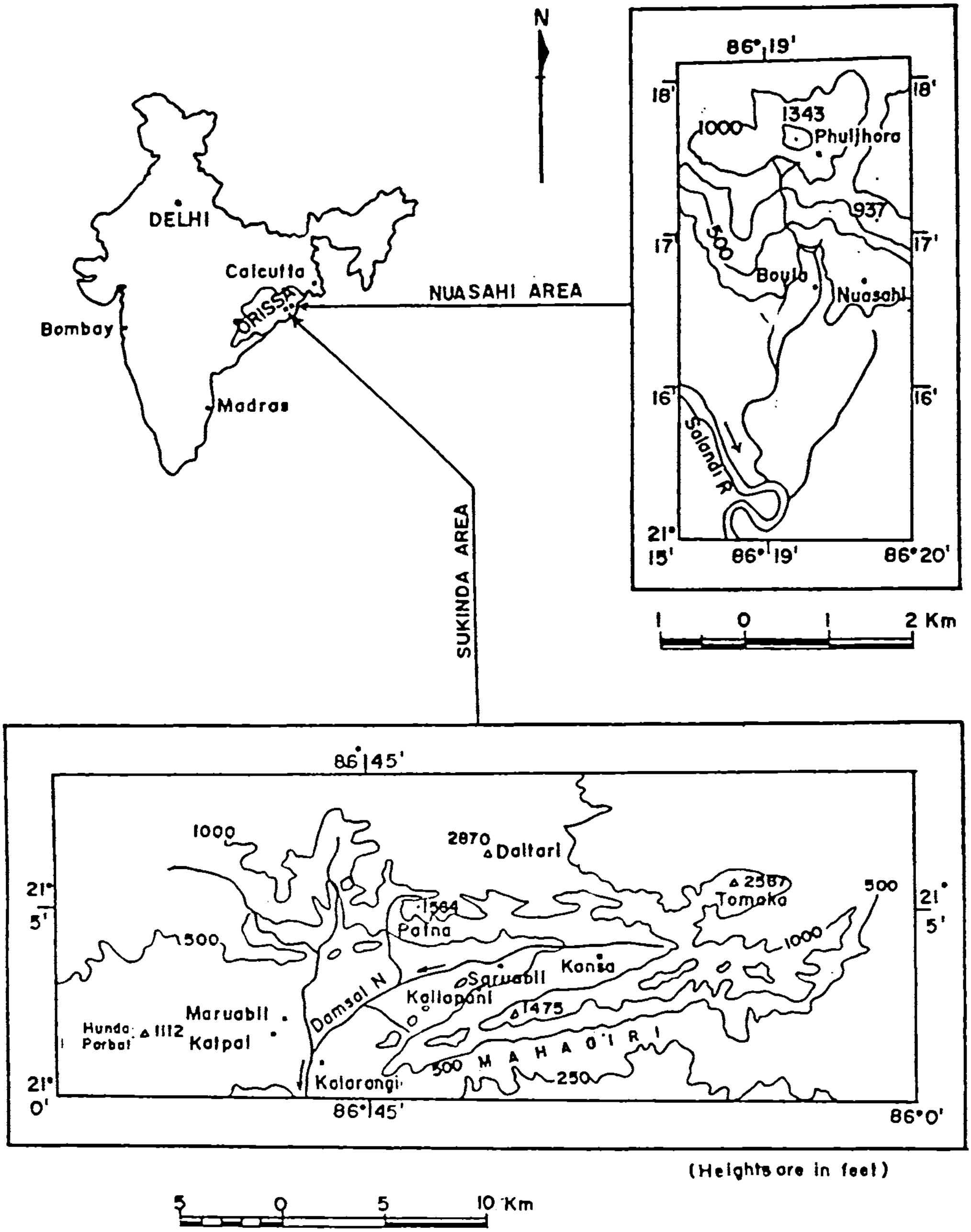

Fig:1 LOCATION MAP OF CHROMITE - BEARING ULTRAMAFICS OF ORISSA

FIG.2 GENERALISED GEOLOGICAL INTERPRETED MAP OF SUKINDA ULTRAMAFIC COMPLEX

SCALE - 1 : 1,00,000

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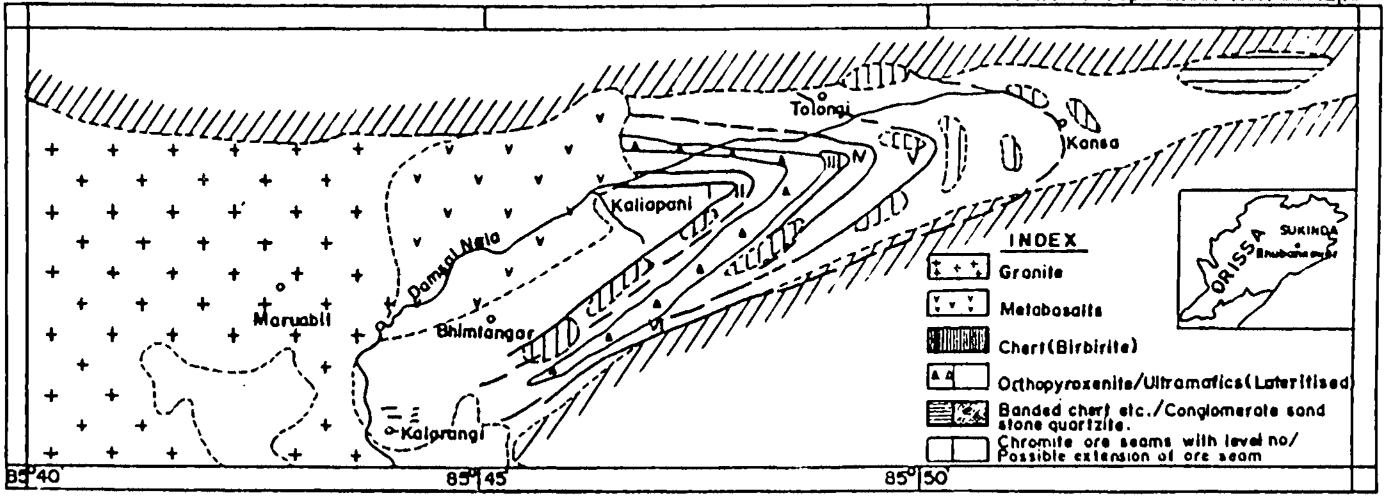

Tolongi
Kansa
Kaliapani
Damsal Nala
Maruabil
Bhimtangar
Kalarangi
N
INDEX
Granite
Metabasalts
Chert (Birbirite)
Orthopyroxenite/Ultramafics (Lateritised)
Banded chert etc./Conglomerate sand stone quartzite.
Chromite ore seams with level no/ Possible extension of ore seam
ORISSA
SUKINDA
Bhubaneswar
85°40
85°45
85°50

SOURCE : FROM SGAT SYMP VOL ON Chromium & Nickel, 1990

Bidyadharpur barrage and Agarpara. The important features of the area include a dam on Salandi river and a barrage at Bidyadharpur. The topographical expressions range between 90m and 400m aMSL.

About 70 kilometers south west of Boula-Nuasahi lie the chromite deposits of Sukinda ultramafic belt of Jajpur-Dhenkanal districts. Located in a E-W trending valley flanked on the north by the Daitari hill range and Mahagiri range in the south, the ultramafic belt has an elevation ranging between 166 m and 208m aMSL while the hill ranges rise to over 690 m aMSL. The drainage of the valley is controlled by NE-SW flowing Damsal nala, a tributary of river Brahmani. This belt extends over a length of about 20 kilometers, from Kansa in the east (21° 03' N and 85° 48' E) upto Maruabil (21°02'N and 85° 43' E) in west and covers an area of approx. 40 sq. kms. This chromite deposit was a chance discovery by one of the TISCO workers way back in 1949 and since then prospecting, exploration and mining activities have been carried out in this belt. The nearest railway station on S.E. Railway is Jajpur-Kendujhar Road which is connected by all weather metal roads of 50 kilometers length both from Saruabil (east) and Kalarangi (west) of this belt. Daitari-Paradip Expressway passes at a distance of 10 kms. from the eastern and of the belt.

About 50 kilometers north east of Nuasahi, there is a small occurrence of chromite near Bhalukasuni in Balasore district. All these locations are shown in the Fig. 1.

2. Geological Set up

Indian chromite deposits occur as bands, lenses and pockets in the serpentinised dunite-peridotite except in Salem district where it occurs in association with anorthosites. The ultrabasic rocks are all of Precambrian age parallel or subparallel to major tectonic zones of Peninsular India and are intrusive into the pre-existing sediments and volcanics, subsequently regionally metamorphosed and tectonically deformed.

The Sukinda ultramafics as well as the igneous complex of Boula -Nuasahi are intrusive into the Precambrian metamorphites, namely, the quartzites and quartz-muscovite-sericite schists. Both are well differentiated layered igneous complexes.

2.1 Sukinda Ultramafic Belt

The chromite bearing ultramafics of Sukinda area (Fig.2) have intruded into the Precambrian metamorphites in the form of a lopolith. The intrusive has a width of 2-5 kilometers and extends for about 20 kilometers in a ENE-WNW direction from Kansa in the east to Maruabil and beyond in the west. The ultramafic body consists essentially of magnesite-rich dunite-peridotite with the chromite bands and subordinate amount of pyroxenite devoid of chromite mineralisation. The basic differentiate is practically absent. The pyroxenite is relatively fresh but the dunite-peridotite members are highly serpentinied and intensely lateritised giving rise to a nickeliferous laterite profile of variable thickness. There are as many as six chromite seams, fairly thick and persistent both along strike direction of the intrusive and with depth as observed in the quarry and bore-hole sections from Saruabil in the east to Bhimtangar in the west. Further west at Kalarangi, Kathpal, Maruabil the chrome ore bodies do not exhibit any regular alignment, rather these are exposed in disjointed bands and lenses apparently disrupted by the emplacement of younger granite. The granite is exposed at several places around Maruabil and also encountered in the bore hole sections at the western part of TISCO's quarry, Kalarangi and Kathpal mines.

A generalised **Stratigraphy** of Sukinda ultramafic complex (Sahoo, 1974) is as follows;

Recent to Pleistocene		Soil, Alluvium Laterites
Unconformity		
		Dolerite Granite Gabbro-diorite
Precambrian	Ultramafics	Pyroxenite Dunite-peridotife with chrome ore
	Meta-sediments and meta-volcanics	Gritty quartzite Meta-Volcanics
Base not seen		

Small exposures of diorite rocks are found in Kathpal and Bhimtangar, Besides, several dolerite dykes have intruded into the ultramafics, quartzites as well as the granites. This happens to be the last stage of igneous activity in this Precambrian terrain. Soil, alluvium and laterite of recent origin are overlying the ultramafics uncomformably.

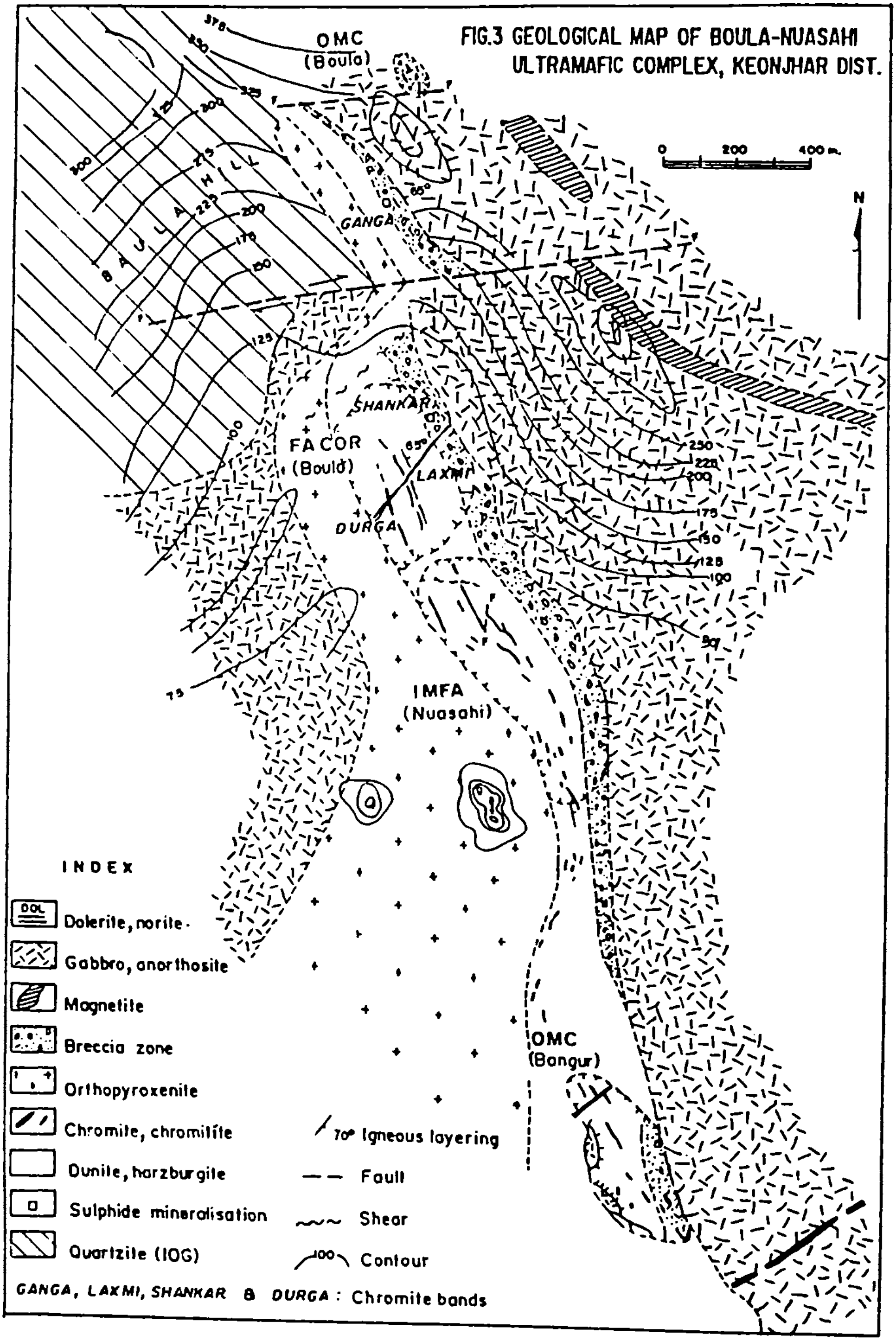


FIG.3 GEOLOGICAL MAP OF BOULA-NUASAHI ULTRAMAFIC COMPLEX, KEONJHAR DIST.

2.2 Boula-Nuasahi Complex

The area around Boula-Nuasahi consists of older quartzites which include massive, ferruginous and micaceous varieties. The intrusives into these Precambrian metasediments are a suite of dunite- peridotite-pyroxenite rocks with less magnesium and pronounced gabbroic differentiate, a younger granite and a still younger swarm of dolerite dykes (Fig.3)

The ultramafic body to the west of village Nuasahi extends for about 3 kilometers in a NNW-SSE direction from Phuljhora Huli (1343') down to the village Jauthabahali. This is a dyke like steeply inclined body having distinct intrusive relationship with the older quartzite and epidiorite hills to the north. The ultramafic body has a maximum width of about 1 kilometer in the middle tapering gradually towards north and south and mainly consists of a serpentinised dunite-peridotite core and a subordinate amount of pyroxenite, almost in a bysmalith form.

The chromite bodies occur in the form of discontinuous bands and lenses, well exposed in the mines at the central part and confined to the altered dunite-periodotite. These bands have a NW-SE to NNW-SSE strike with moderate easterly dip, and an average width of 5 meters. These discontinuous bands as well as the lenses of chrome ore occurring to the north and south have been affected by shearing and faulting during post consolidation stage. The Stratigraphy of Boula-Nuasahi igneous complex (after Sahoo, 1963 and Mohanty, 1994) is as follows:

Recent to Pleistocene		Soil, Alluvium Laterite
	Unconformity	
Precambrian	Ultramafics	Dolerite dykes Granite Granophyre Gabbro-anorthosite with Ti-V magnetite ore bodies Enstatite-Peridotite and dunite with chrome ore
	Meta sediments and metavolcanics	Quartzite, quartz-mica schist, quartz-sericite schist
	Base not seen	

It is seen that the stratigraphy of Sukinda ultramafic belt bears a striking resemblance to that of Boula-Nuasahi igneous complex and fits well to the geological sequence of southern Singhbhum and north Orissa of Krishnan (1956) as well as Singhbhum-Orissa Iron ore craton as proposed by Saha (1988). The stratiform nature of both Sukinda and Boula-Nuasahi chromite occurrences is well established. Their derivation from a single magma source where Sukinda ultramafics is the earlier intrusive and Boula-Nuasahi complex is the later derivative is suggested.

2.3 Bhalukasuni

Small bodies of chromite associated with serpentinised ultrabasic rocks occur as enclaves within gabbro-anorthosite and hornblende granite-granophyre suite of rocks near Bhaukasuni village in Nilgiri sub-division of Balasore district. Shallow bodies of chromite excavated by the Directorate of Mining & Geology has yielded Cr_2O_3 ranging from 26% to 54.8%. Drilling undertaken by the DMG has not intersected any chromite bodies at depth. G.S.I. has taken up drilling to locate concealed ore bodies, if any, below thick blanket of laterite in the area.

3. ORE BODIES

3.1 General Features

The Sukinda ultramafics is characterised in having fairly thick (10-50m.) chromite seams. Six seams have been deciphered. The seam dipping south into the Mahagiri hill is hard, lumpy and very fine grained. The rest of the seams dip to the north at steep angles, essentially friable in nature and are described as brown ores. The first brown ore horizon (Seam 1) is perhaps the thickest (40m.) seam in the world.

The chromite seams in the Boula-Nuasahi area are much thinner (5 to 10m.), smaller and mostly hard and lumpy. They also persist with depth of more than 100 m as observed in a few bore hole intersections.

These ore bands and lenses are confined to peridotite rock with sharp contact at the footwall side and towards the hanging wall side the contact is gradational. There are several references to presence of scour/slump structures in the chromitite horizons of the Sukinda and Nuasahi that is characteristic of gravity controlled magmatic layering.

The pyroxenite horizon is conspicuous by the absence of chromite mineralisation. Except in the Bushveld complex, the chromite principally occurs in the olivine rich rocks and is rare in pyroxenites.

3.2 Classification of ore deposits

Chromite deposits have been classified broadly into two groups, viz. Stratiform and Alpine type. Stratiform deposits are sheet-like or lopolithic in form, extend over large area and characterised by both rhythmic and cryptic layering, thickness of individual layers varying from a few cms to several metres. Bushveld complex of South Africa, the Great Dyke deposits of Zimbabwe, Sukinda and Boula-Nuasahi deposits of India belong to this group. The stratiform deposits account for about 90% of the total chromite resources. The podiform deposits (type of Alpine deposits) are characterised by irregular form such as pods or lenticular, limited extension, small reserve and high chromium content The typical deposits are found in Albania, Turkey, Philippines, Pakisthan, Greece and Urals.

Depending on compositional variation, chrome ore can be divided into the following three categories;

	% Cr_2O_3	Al_2O_3	Cr:Fe
High chromium	46-55	-	Over 2
High iron	40-46	-	1.5-2
High aluminium	32-38	22-34	2-2.5

Resources of high aluminium chromite are negligible. Orissa deposits are predominantly stratiform, high chromium and high iron types.

Based on physical characteristics, Orissa deposits can be classified under the following five categories:

i) Lumpy and granular - This type of ore is hard, compact, medium to fine grained. This ore is found all along the sixth seam(southern-most of the six seam sequence) at Kathpal and to a limited extent at Kalarangi, Kaliapani and Saruabil in Sukinda belt. In Boula-Nuasahi area, this ore type is plentifully found in the central part, but towards the north the ore is fine grained and massive. The gangue mineral in this ore is invariably talc-serpentine minerals occupying the grain interstices and the fractures.

ii) Friable ore - This is soft and powdery in nature, mostly of the higher grade (Cr_2O_3> 50%) with very little gangue minerals and is the bulk constituent of all the brown ore horizons in Sukinda belt. The serpentine matrix has been leached away from the grain interstics and fractures during lateritisation causing friability to the chrome ore in these high grade brown ore horizons.

iii) Ferruginous ore - Considerable portion of upper portions of ore bodies in the Sukinda belt (around Bhimtangar, Sukerangi, Kalarangi) and in the southern part of the Boula-Nuasahi complex are lateritised giving rise to ferruginous chrome ore where mostly goethite and to some extent hematite form the gangue minerals. Goethite and hematite serve as cementing material making the ore hard and compact.

iv) Banded ore - This type of ore is generally encountered in the wall rocks of chromite bands where both chromite and olivine rich layers alternate

v) Disseminated ore - This type of ore has essentially altered to serpentine as the gangue mineral evenly distributed in it giving rise to white spots. The miners often call this "spotted ore"

Both banded and disseminated ore are lower in Cr_2O_3 content (less than 30%) and respond very well to gravity separation yielding good concentrates. On the otherhand, the ferruginous ore pose some difficulty in complete removal of goethite / hematite gangue through gravity technique.

iv) Magnetic ore - This type of chrome ore is found only in the Boula chromite mines of FACOR in their "Ganga" lode, where both chromite and magnetite are fine grained intimate admixture, posing problem in their separation. The average Cr_20_3 content is 22% and Cr: Fe ratio is 0.69.

3.3 Texture and Mineralogy

The dunite-peridotite rocks in both the intrusives are highly serpentinised, giving rise to antigorite together with certain amount of chrysotile and lizardite. Development of typical mesh texture pseudomorph after olivine is very common. On the otherhand, the pyroxenite is only marginally altered. Thus serpentinite, talcose rocks both massive and schistose varieties are the altered products. Serpentinisation decreases towards depth as more and more relict olivine is observed in bore hole sections of altered dunite peridotite at Kansa, Saruabil. Kaliapani, Bhimtangar, Kalarangi (all of Sukinda belt) and Nuasahi-Boula

General observations from the textural studies of the ores and the primary silicates of both the intrusives suggest preference for development of mono-mineralic assemblages, that is olivine in dunite-peridotite, chromite in massive chromitite and enstatite in pyroxenite. Bi-mineralic assemblages may be olivine +chromite or olivine +pyroxene. These minerals occur dominantly as cumulus phases with pronounced idiomorphic crystals.

Presence of kink bands in olivine and fine exsolution lamellae of clinopyroxene in the (100) optic plane of enstatite as seen in thin sections of dunite and pyroxenite is indicative of their development under stress during slow cooling of the pluton.

Concomitant with the serpentinisation taking place at sufficiently low temperature (300°) there is formation of secondary silicates, carbonates, chert and opaque minerals.

Both greenish uvarovite (Cr-garnet) and pinkish kraemmererite (Cr-chlorite) are found as fracture fillings in the chrome ore at Bhimtangar, Kalarangi and Sukerangi. In Nuasahi-Boula area, presence of greenish chrome mica (fuchsite) is seen to be associated with vein quartz only. All these indicate limited mobility of chromium and rules out any hydrothermal origin for the major chromite ore bodies.

Chromite, particularly the accessory chromite has undergone metasomatic replacement during the serpentinisation stage and even earlier when the intrusive was still hot. This alteration product is seen around the margin and fractures of the chrome ore spinel. Several workers have named it ferrit-chromite which is relatively enriched in iron and depleted in magnesia and alumina. This phenomenon is well observed in the rock and ore sections of both the intrusives.

Further, the chromite in both these belts are intensely shattered, mylonitised and fractured, more so in the case of Sukinda ores. This is caused by the tectonic events which started earlier to serpentinisation as is evidenced by the filling of serpentine in the fractures and veins.

4. EXPLORATION

During the 1960s, following geophysical (gravity) survey carried out by the G.S.I. in Sukinda valley, drilling was carried out on a few anomaly points and some proved to be positive as in Kaliapani leasehold of OMC.

In view of stratiform nature of Sukinda as well as Boula-Nuasahi chromite deposits, the ore bodies in both the cases gave the promise of their continuity along strike and dip directions. This conceptual ore search was stressed upon during detailed regional reassessment made jointly by the Geological Survey of India as the nodal agency supported by Mineral Exploration Corporation, Directorate of Mining and Geology, Government of Orissa and the Orissa Mining Corporation. By and large the exploration/drilling has been made down to 100 m depth. This exploration was initiated during 1976 and continued till 1982.

The techniques of exploration adopted comprise large scale mapping, drilling to prove strike and depth continuity, sampling and analysis

Drilling is being undertaken intermittently by the G.S.I to prove the continuity of ore bands in the southern limb of the fold (south of Damsala stream) both along strike and in depth. Besides DMG, TISCO, OMC and FACOR carried out exploration by drilling in the respective leaseholds to prove reserves for production planning. On the basis of results of exploration carried out by the G.S.I., MEC, DMG, OMC, TISCO, and FACOR, the Expert Committee constituted by Government of India reassessed the reserves of chrome ore in Orissa. The exploration gaps have also been broadly identified. These for Sukinda deposits are:

(1) Drilling at interval of 400 m to prove strike continuity and at different depths to intersect the ore bands below 100 m vertical depth.

2) Geotechnical and geohydrological investigations required for planning underground mining.

5. RESERVE AND GRADE

The world resources of chrome ore are of the order of 7,500 million tonnes, of which Republic of South Africa and Zimbabwe account for 85% and 10%. Although India with a geological resource of 186 million tonnes account for only 2.5% of world resources, chrome ores of Sukinda valley of Orissa State have a distinct edge over other major deposits of the world in terms of quality, large widths of ore bands and amenability to simple beneficiation process.

5.1 Orissa Reserve

Of the total geological resources of 186 million tonnes in India, Orissa accounts of 182 million tonnes i.e. 98% and bulk of it are confined to Sukinda ultramafic belt.

The depth-wise break-up of resources has been reassessed by the Expert Committee constituted by the Department of Steel, Mines (now called Ministry of Steel) in 1989.

Computation of resources is based on the following parameters

1) The "Resource" include "Reserve" (quantity of ore estimated to be available down to a depth of 100 m) plus " conditional resource" (estimated quantity below 100 m depth excepting Boula leasehold of FACOR where mining is being done below 100m)

2) Cut off ranging from + 10 to 30% Cr_2O_3.

3) Depths ranging from 30 m to 250 m and with a very few intersections below 100 metres.

On the basis of above parameters, estimates of sector and lease-wise resources of chrome ore as on 1.4.90 are recorded in the following table:

Table 1 : Sector and lease wise Resources

Sector/Lease	Resources (in million tonnes)	Minimum depth of estimation
A. Sukinda		
Kamardah (B.C. Mohanty & Sons)	2.20	150m
Saruabil (Misrilal Mines)	9.47	200m
Sukerangi(OMC)	7.54	200m
Kaliapani(OMC)	10.31	+100m
South Kaliapani(OMC)	25.14	115m
Bhimtangar(TISCO)	98.91	250m
Chingripal(IMFA)	0.86	100m
Talangi(OMC)	8.66	+100m
Gurjang(IDCOL)	0.41	65m
Gurjang(FACOR)	3.63	135m
Gurjang (AIKAT)	0.33	100m
Kalarangi(OMC)	0.86	100m
Kathpal (OMC)	0.27	50m
Kathpal(FACOR)	0.12	100m
B. Boula-Nuashi		
Boula(OMC)	0.06	15m
Boula (FACOR)	8.24	225m
Nuasahi(IMFA)	1.55	30
Bangur (OMC)	0.85	60m
C. Bhalukasuni	0.0003	

There are a few other deposits such as Dangakata, Maulabhanja, Oulinaga-Ekul-Kentol, Birasal in Dhenkanal district. The total estimated resources of all these deposits are about 0.27 million tonnes. The total estimate do not include the resources in a 40 hectare block in Nuasahi sector of Keonjhar held earlier under lease by M/s Serajuddin & Co.

6. COMPOSITION

Sukinda chromite is relatively rich in chromium and magnesium contents, does not exhibit pronounced variation in the spinel constituents of different horizons and invariably has Cr/Fe ratio of more than three,. Boula-Nuasahi chromite has comparatively lower Cr_2O_3 and MgO contents, higher iron content and higher incidence of Ti and V. Accordingly, the Cr/Fe ratio is 2:1 to 1.6:1, excepting the magnetic ore of the Ganga lode where Cr/Fe ratio is less than 1. Thus, there is a regular variation in the grade of the chromites from the lower to the higher horizons in this deposit. Nickel content in the spinels of both deposits are invariably between 0.01 to 0.03 percent and platinum content around 20 to 40 ppb. The composition of a few chrome spinels is described later. Cr_2O_3 content of spinels of Sukinda & Boula-Nausahi when plotted in the Thayer's diagram (1970), their stratiform nature is very well understood. Further Sukinda ore is comparable with Great Dyke ore while Boula-Nuasahi ore is comparable to Bushveld chromite.

Table 2 : Chemistry of the clean chrome spinels from Orissa

Location	Cr/Fe ratio	Cr_2O_3	MgO	FeO(t)	Al_2O_3	TiO_2	V_2O_5	Total
Sukinda	3.35	57.5	14.01	15.12	12.6			99.32
	3.30	58.7	12.57	15.57	11.82	-	-	98.83
	3.86	58.9	16.1	13.4	10.7	0.00	0.1	99.35
	3.30	56.6	11.7	15.9	11.1	0.05	0.06	98.44
	3.44	59.4	11.41	15.2	12.7	0.18	0.14	99.03
Boula-Nuasahi	2.04	54.9	11.64	23.7	9.82	0.27	0.1	100.43
	1.8	52.8	10.5	25.65	9.8	0.3	0.1	99.15
	1.67	49.4	8,89	26.08	14.4	0.62	0.25	99.72

Analysis of some typical friable ore and concentrates produced in Sukinda mine of TISCO are given here.

Table - 3

	Friable ore (R.O.M)			Concentrates	
Cr_2O_3	51.50	50.16	47.50	53.0	60.1
Cr/Fe	2.82/1	2.61/1	2.35/1	2.65/1	3.88
SiO_2	4.80	5.2	6.02	2.04	1.45
Al_2O_3	11.74	12.55	13.53	10.6	8.50
MgO	11.75	11.65	11.83	11.84	11.83
CaO	0.5	0.5	0.5	1.26	0.60
P	0.006	0.006	0.006	0.006	0.006
S	0.007	0.007	0.007	0.007	0.007
Size	0.75mm	0-75mm	0-75mm	0-1mm	0-1mm

7. MINING

In Orissa, 18 leases have been granted for mining of chromite covering an area of 78.39 sq. kms, Of these, 14 are in operation. The lessees include TISCO, OMC, FACOR, Misrilal Mines, B.C. Mohanty & Sons, IDC of Orissa Limited and IMFA Group. Fig. 4 exhibits the locations of mining leases

Excepting Kathpal mine of FACOR, all mines in Sukinda sector are opencast. The maximum depth attained is 64 metres in the opencast mine of TISCO. Quite a few quarries have been abandoned after attaining depths of 40-60 metres. The quarries can not be backfilled as ore persists with depth. The present ore: overburden ratio is 1 tonne: 8-10 M^3. Machine mining has been resorted to enable mining operations to continue upto maximum 100m depth.

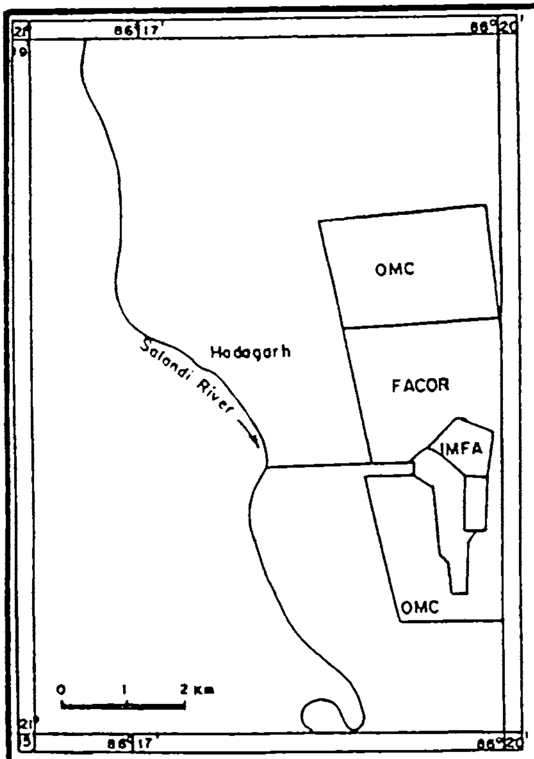
Continuation of mining at depth (say beyond 70m) is beset with a number of problems. These are;

i) weak wall rocks and friable nature of ore,
ii) possibility of slope failure and landslides,
iii) limited space availability for disposal of large volume of overburden,and
iv) profuse percolation of water.

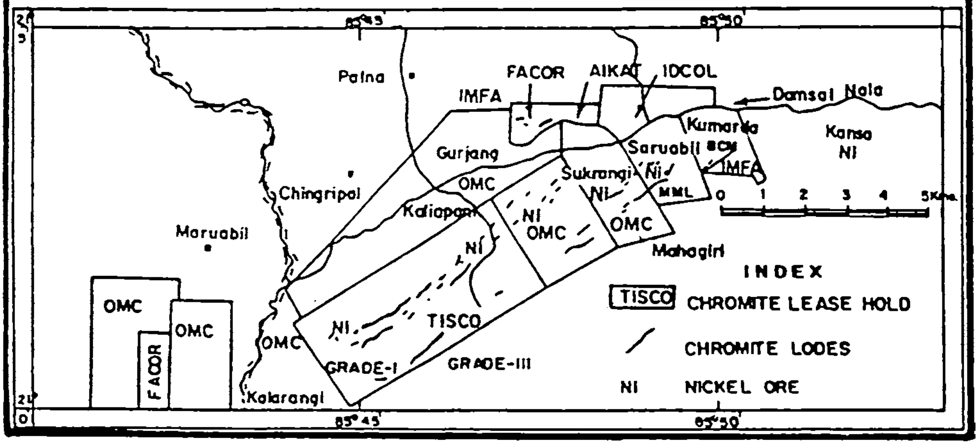
Mechanised mining operations involve drilling (100mm & 150 mm

FIG. 4

CHROMITE MINES, DISTRIBUTION OF CHROMITE & NICKEL ORE IN BOULA - NUASAHI AND SUKINDA BELTS



BOULA - NUASAHI



SUKINDA

dia) and blasting using delay detonators, removal of OB and ore by hydraulic excavator-dumper combination. The OB benches are maintained at 6m-8m height. The ore benches are 3 m high. The pit slope is restricted to maximum 30°

In manual workings, the bench height is maintained at 1.5m.

In Boula-Nuasahi sector, three mines are in active operation. Here, chromite is mostly lumpy and the wall rock is hard serpentinite. FACOR adopted underground mining in Boula in 1981 concurrently with opencast mining. The max. quarry depth attained is about 90 m from the surface. The dimensions of the manual and mechanical benches are 7.5 m (height), 6 m (width) and 10 m (height), 10-12m (width). The stripping ratio is 1 tonne: $20m^3$ of OB. Mining and haulage are done by drilling (100mm dia) and blasting, diesel operated rope shovels/track shovels/ hydraulic shovel/front end loaders and dumper combination. Underground mining consists of aditing and sub-level caving; incline, vertical shaft; levels, sub-levels and cross-cuts. The machineries deployed include winder, long hole and DTH drills, mechanical loaders, load haul dumpers, locomotives and mine cars, fan for ventilation, multi-stage turbine pumps.

The other two mines in this sector, viz. Nuasahi of IMFA and Bangur of OMC are opencast. In both these, underground mining is contemplated.

8. BENEFICIATION

In the course of producing directly usable chrome ore (+38% Cr_2O_3) for domestic metallurgical, refractory and chemical industries and for export, large quantities of low/sub-grade ore (10-38% Cr_2O_3) are extracted from the mines in the State. From the point of view of conservation of the valuable chromite resources and for optimum utilisation of the products of mining, beneficiation is imperative. Taking advantage of the higher specific gravity of chromite vis a vis siliceous gangue, manual beneficiation by simple washing and panning is being practised in several mines in the State.

The low grade ores are either siliceous or ferruginous, having serpentine, talc, goethite, limonite as the major gangue minerals with traces of chert, magnesite, magnetite, maghemite. While chemical composition of the spinel determines the extent to which the ore can be upgraded, the nature of the gangue minerals including their liberation size indicates the method that is suitable for particular ore type. Several studies on the beneficiation of these low grade ores have been undertaken at RRL, Bhubaneswar, BARC, IBM and NML. These studies suggest that effective beneficiation can be achieved through simple size reduction and screening or gravity separation techniques like jigging, tabling, spiralling and classifying.

As the effective liberation size (d_{80}) for most of these ores is in the range 0.15mm to 0.075 mm and a sizeable portion (10 to 15%) is below 50 microns, the undersize fraction escapes to the tailings or go in the slimes. These superfines can be recovered by the use of Bartles-Mozley cross belt concentrator. The beneficiation plants are seriously considering to adopt this.

FACOR, TISCO and OMC have set up fully mechanised beneficiation plants. The particulars are as follows:

Table- 4

Agency	**Location of the plant.**	**Rated feed capacity & grade.**	**Projected output of concentrate and grade.**
FACOR	Boula	1,00,000 tpa 15-21% Cr_2O_3	22,000 tpa 42-45% Cr_2O_3 Cr/Fe : 1.4-1.7
TISCO	Bhimtangar	300.000 tpa -38% Cr_2O_3 (Normally 25-30% Cr_2O_3)	1,05,000 tpa 50 ± 2% Cr_2O_3 Cr/Fe : 2.6-30
OMC	Kaliapani	1.65,000 tpa (30-35% Cr_2O_3	84,000 tpa (52-55% Cr_2O_3)

The magnetic ore of Boula has not responded to the conventional beneficiation processes as the chromite-magnetite intergrowth is on micron scale.

The concentrates (products of beneficiation) as well as naturally occurring medium and high grade friable chrome ore have to be agglomerated before they could be utilized in the manufacture of ferrochrome. As a matter of fact, the feed to the charge chrome plants of FACOR near Bhadrak and of TISCO at Bamnipal consist of part briquettes and pellets.

9. ENVIRONMENTAL CONSIDERATIONS

Chromite mining activity in Orissa has caused loss of soil cover, degradation of land surface, denudation of forests, displacement of fauna particularly wild animals and certain extent of pollution to water on account of incidence of hexavalent chromium in excess of the permissible limit of 0.1mg/litre in the mine water discharge. A major problem is generation of huge amount of waste during production of chromite and lack of dumping space. These and other incidental problems have been studied by MECON and both regional and lease specific Environmental Management Plans formulated in accordance with the guidelines prescribed by the Ministry of Environment & Forests of Government of India.

10. USES AND SPECIFICATIONS

Chromite is the sole commercial source of chromium. It has a wide range of applications in metallurgical, chemical and refractory industries. Production of stainless steel and non-ferrous alloys are two of its more important uses. The properties that render the use of chromium so versatile and indispensable are resistance to corrosion, oxidation, wear and galling; enhancement of hardenability.

In metallurgical industry, chromite is used for production of low carbon and high carbon ferrochrome. With the introduction of AOD process in stainless steel making, the preference is for use of low cost charge chrome (low chromium HC Fe Cr with higher silicon) which can be produced from lower grade chromite.

In the refractory industry, chromite is used in the form of chemically bonded, burned or fusion cast chrome-magnesite and magnesite-chrome bricks in iron and steel, glass, cement and non-ferrous alloy making.

Sodium dichromate is the primary chromium containing product of the chemical industry. The chrome-chemicals are used in chromium plating, leather tanning, drilling muds, as dyes, catalysts and pigments.

The Expert Group on Classification of Minerals with regard to their possible optimum use constituted by the erstwhile Department of Mines of Government of India has recommended the following end use specifications of chromite (1987).

Metallurgical

a) Ferrochrome	Cr_2O_3	48%(min)
	Cr:Fe	2.8:1 (Min)
b) Charge chrome	Cr_2O_3 :	44% (Min) *
	Cr:Fe :	1.6 : 1(Min)

(* Chromite containing 42% Cr_2O_3 with Cr:Fe of 1.4:1 are being used for production of charge chrome). The ore should be lumpy. Friable ore can be used after agglomeration.

Refractory.

Cr_2O_3	40% (min)
Al_2O_3	14% (max)
FeO	20% (max)
SiO_2	Less than 10%
Ca0	1% (Max)

The ore should be lumpy.

Chemical.

Cr_2O_3	44% (min)
FeO	20% (max)
CaO	3% (max)
MgO	14% (max)
Al_2O_3	14% (max)
SiO_2	7% (max)

11. PRODUCTION, CONSUMPTION AND TRADE

The current annual production of chromite in the State is of the order of 1 million tonnes (1993), which constitutes about 98% of the total production in the country. Export from the State has been of the order of 250,000 tonnes annually. The grade-wise production break-up during 1993 was of the following order:

	('000 tonnes)
+47% Cr_2O_3	406
40-47% Cr_2O_3	328
30-40% Cr_2O_3	223
-30% Cr_2O_3	14

Domestic consumption of chromite in the country accounts for nearly 70% of the total production and are in the following areas:

a. Low carbon and high carbon ferrochrome and silicochrome
b. Chargechrome
c. Refractories (including iron and steel and alloy steel)
d. Chemicals
e. Others (cement, ceramics, foundries and chrome metal)

Chromite produced in Orissa practically meets the requirements of the above industries located in different parts of the country. Bulk of the consumption within the State is shared by the following units;

i) Three 100% EOU charge chrome plants each of 50,000 tpa capacity located at Bamnipal (TISCO), Randia near Bhadrakh (FACOR) and Choudwar (ICCL)

ii) Ferrochrome plants of IDCOL at Jajpur Road and IMFA at Theruvali

iii) Refractory plants at Rajgangpur (OCL), Belpahar (TRL) and Latikata (OIL)

Judging the current trend of consumption in the country and the anticipated growth, the annual demand around 2000AD is likely to be of the order of 1 million tonnes. Export of chromite in limited quantity is expected tc be continued. The annual export quantum envisaged is 300,00 tonnes, Thus the future domestic and export demand can be met by augmenting the current level of production by about 30%.

B. NICKEL ORE

1. General

Owing to its critical and strategic nature of applications, the demand for nickel in the country is steadily increasing. Annual consumption of nickel in the country at present is of the order of 10,000 tonnes and almost the entire quantity is met through imports at a cost of around Rs. 3,000 million in equivalent foreign exchange. The estimated demand by the turn of the century is projected at 15,000 tonnes. Conscious efforts are therefore being made by the Government of India to utilise the indigenous resources of nickel ore in Sukinda ultramafic complex in Orissa state, which as of today constitute the only commercially workable prospect in the country. Fig. 1 shows the locations of the nickel ore occurrences.

2. Geology

The Sukinda ultramafic body as described earlier in the chapter on chromite is stratiform in nature and comprises interlayered nickel and chrome rich dunite-peridotite and orthopyroxenite with no chromite and nickel mineralisation. The serpentinised dunite-peridotite members have been subjected to intense chemical weathering resulting in the formation of a nickel rich limonite cover with relict serpentinite and talc-schist. The primary chrome ore bodies confined to these limonitic horizons have also undergone weathering and given rise to friable chrome ore. The lateritised ultramafites have been silicified giving distinct cherty horizons as well as disseminations.

On the basis of rock exposures in the mine faces and sub-surface data obtained from core drilling, the following sequence of lithologic units has been established for the lateritic profile in Sukinda belt, (GSI)

Lateritic Soil
Disintegrated laterite
Pisolitic laterite
Limonitic nickel ore
Serpentinous nickel ore
Friable chromite
Talc-serpentine rock
Lumpy chromite
Serpentinised dunite-peridotite

A typical profile of nickeliferous limonite in Sukinda consists essentially of three zones, namely,

1st zone

A dark brown to coffee-brown laterite top layer with/without ferruginous concretions usually 1 to 5 metres thick having nickel content of around 0.5 percent and principal minerals like hematite and goethite.

2nd zone

The next lower zone of yellow to yellowish brown laterite is soft, mostly limonitic (fine grained and poorly crystalline goethite) highly porous with nickel content varying between 0.5 to 1.5 percent. This zone has a considerable thickness varying between 20 to 60 metres.

3rd zone

The second limonitic zone merges downwards to clay serpentinite transitional zone of a smaller but variable thickness with nickel content of 1 percent imperceptibly grading to nearly fresh but well jointed serpentinite-dunite bed rock. This is seen only in Kansa and Saruabil sector.

The nickel and the friable chrome ores occur in close association in Saruabil-Kaliapani-TISCo sectors. In the Kansa sector, the nickel ore body is not associated with chromite. The friable chrome ore is really the product of weathering which has also led to the formation of limonitic nickel ores in the valley lying mainly to the south of Damsala nala, extending from Kumardah in the east to Bhimtangar in the west over a strike length of 15 km. and with an average width of 1km.

3. Exploration

The incidence of nickel in the weathering profile of Sukinda ultramafic complex was first brought to light by the I.B.M. during 1962. Exploration by means of large scale mapping and drilling was first carried out by the G.S.I. to ascertain the depth persistence and grade of nickel in Kansa area during 1965-67. The drilling grid adopted ranged from 200m to 50 m. Deep pits have been sunk to ascertain the nature and thickness of overburden, to collect bulk samples for various types of tests. Exploration by drilling has been carried out by the Directorate of Mining & Geology in Kansa extension block to ascertain Cr & Ni mineralisation. In the working mines in Sukinda sector, investigation has been carried out by OMC, DMG, MECL, Tata Steel, GSI, IBM and RRL(B) by means of sampling of mine faces, ore and overburden stacks to assess the incidence of nickel and their reserves.

4. Reserves

On the basis of exploration carried out, category wise and grade wise reserve of nickel ore at various cut-off have been computed by the G.S.I. as indicated in the following table.

Table 5 : Nickel reserves in Sukinda Valley (associated with friable chrome ore).
(in million tonnes)

Sector	Cut-off (% Ni)	Prov- Res.	Gr. %	Prob. Res.	Gr. %	Possible Res.	Gr. %	Total Res.	Gr. %
Kaliapani	0.9			25.24	1.09	6.28	1.07	31.52	1.09
	0.7			34.96	0.99	8.06	1.01	43.02	0.99
	0.5			53.32	0.87	11.27	0.91	64.59	0.88
Kamarda-	0.9			6.13	1.17	4.35	1.16	10.48	1.17
Sukerangi-	0.7			9.13	1.01	4.86	1.12	13.99	1.06
Saruabil	0.5			13.38	0.87	5.05	1.05	18.43	0.92
TISCO	0.9			3.60	1.32	43.0	1.22	46.60	1.23
	0.7			6.20	1.05	57.7	1.03	63.90	1.03
	0.5			-(over 120 million tonnes)					
TOTAL	0.9			34.67	1.13	53.63	1.20	88.60	1.18
	0.7			50.29	1.00	70.62	1.03	120.01	1.02
	0.5			66.70	0.86	16.32	0.95	83.02 +120.00	0.89

The reserves computed have been discounted by 20% to take care of voids, barren zones, deleterious bands etc.

Table 6 : Nickel reserves in Kansa sector (not associated with chromite)
(in million tonnes)

Cut-off (% Ni)	Reserve (proved + probable)	Mineable Reserve	Grade (% Ni)
0.9	20.84	16.67	1.00
0.7	30.07	24.06	0.9
0.5	40.88	32.74	0.8

In Simlipal ultramafic complex of Mayurbhanj district, probable reserve of 27 million tonnes of lateritic nickel ore at 0.5% cut off has been estimated by GSI.

5. MINING PRACTICE

Currently about a million tonnes of chrome ore is produced annually in the State. The mining practices adopted have been described in the chapter on chromite. Mining has not been taken up in Kansa deposit where nickel is not associated with chromite.

The soft to medium hard brown-coloured lateritic overburden of top 5 to 10 meters contain less than 0.5% nickel, roughly 30% iron and 5% chromite. Underlying this is soft, light and porous ocherous material essentially composed of goethite, hematite with small amount of magnetite, chert and chromite. The overburden has Ni content between 0.6 to 1.2%. In course of mining of chrome ore, these nickeliferous overburden are removed and stacked separately. As far as practicable, the low grade top layer laterite mantle is dumped separately from the nickel rich lateritic overburden.

In Sukinda chromite mines of TISCo, present level of production of chrome ore is around 5,50,000 tonnes of which friable chrome ore constitutes 400,000 tonnes. The generation of nickeliferous overburden is about 10 cu.m per tonne of friable chrome ore produced. Thus generation of overburden in TISCo sector is of the order of 4.0 million cubic meter per year.

Current production of chrome ore from South Kaliapani mine of OMC is around 200,000 tonnes. This is entirely of friable type. The generation of nickeliferous overburden is approximately 1.6 million cubic meter (at the rate of 8 cu. meter/tonne of chrome ore).

Besides, other mines at Sukrangi, Saruabil and Kumardah produce overburden to the tune of 600,000 cu.m. Thus in the valley, nickeliferous overburden (0.6 - 1.2 % Ni) produced annually is of the order of 6 million cubic meter or approx. 9 million tonnes. Nickel being of strategic importance, Government agencies like IBM, DMG, (Orissa), GSI and RRL have persuaded the mine owners as early as 1975 for separate stacking of nickel rich overburden. As a result of this, separate stacking has been adopted by them.

A quantitative assessment of these dumps was done by IBM in May-June, 1992. The following table gives a picture of the overburden stacked in the leaseholds.

Table - 7 : Quantities of nickeliferous dumps at different leaseholds. *

Sl. No.	Name of the mine & lessee	Total No. of dumps	Volume (in '000 cu.m.)	Bulk density (in natural state)	Quantity (in '000 tonnes)
1.	Sukinda Mine of TISCO.	6	12,248	1.72	21,006
2.	South Kaliapani mine of OMC	1	4,911	1.90	9,330
3.	Sukrangi mine of OMC	2	163	1.72	280
4.	Saruabil mine of Misrilall Mines	5	57	1.50	85
	Total :	14	17,379		30,761

* Source IBM's report to RRL, Bhubaneswar, 1993.

6. ORE CHARACTERISTICS

The lateritic nickel ore is of secondary origin and the ore characteristics (physical, mineralogical and chemical) are highly variable. Detailed investigation on ore characterisation samples of Sukinda area have been carried out at Regional Research Laboratory, Bhubaneswar. Salient features are described in respect of three typical samples drawn from TISCO, Kaliapani and Kansa sectors.

6.1 Physical Characteristics

The wide variation in bulk density of these ore samples signifies variation in their mineralogy, particle size as well as porosity and even degree of crystallinity. The bulk density of Kansa ore is lowest and grain density highest which means this ore sample has high porosity and at the same time finer particle size and maximum geothite with minimum of other minerals. On the otherhand, Kaliapani (OMC) ore has the highest bulk density and lowest grain density implying thereby this has less porosity and somewhat coarser partice size with more of associated lighter minerals like chert, kaolinite, talc etc. TISCO ore sample has intermediate values.

In general, the particle size is very fine for these limonitic materials. The particle size distribution down to 300 mesh (BSS) is somewhat even and then the rise is very sharp, more so for Kansa ore, which is not only very fine but almost 90% by wt. is below 2 micron size.

Kansa ore has the highest specific surface area (SSA) both for bulk and - 300# fraction, which means the ore is equally finegrained and cryptocrystalline to amorphous in character, OMC ore has somewhat higher SSA which means TISCO ore is most crystalline of the lot and OMC ore is in between.

6.2 Mineralogical & Textural characteristics

The nickeliferous laterite profile overlying the serpentinised dunite-peridotite bed rock has essentially minerals of secondary origin formed by the process of chemical weathering. These minerals are goethite, hematite, maghemite, magnetite, chert, clay minerals like kaolinite, montmorillonite, talc, serpentinite. Chromite and rarely olivine are the relict minerals present in small quantities.

Distinct bands of chert and silicified box-work have developed within limonitic ore, thus lowering the nickel content, as observed in the valley.

The nickeliferous limonitic ore grades downward into serpentinous nickel ore which is composed of serpentine, iron rich montmorillonite (nontronite as identified by XRD), with minor amounts of goethite, magnetite, maghemite and chromite. This ore is soft, clayey and varies from olive green to earthy green in colour.

The serpentinite grading downward to relatively fresh dunite peridotite forms the bed rock for the nickel-rich zones. The minerals identified in the serpentinites are serpentine, relict olivine with trace of magnesite, talc, chromite, ferrit-chromite, magnetite, chrome-chlorite.

Studies by optical and electron microscopes indicate a fine grain texture of limonitic ore. Amongst all of them, Kansa ore is extremely fine grained, almost crypto-crystalline in nature.

6.3 Chemical Characteristics

The bed rock as well as the overlying nickeliferous laterite samples have been analysed . The results are presented in the following tables.

Table 8 : Compositional change in laterite profile in Sukinda valley.

[a] Bore hole SN-D, north of Saruabil

	D-4	D-18	D-32	D-38	D-44
SiO_2	29.90	10.00	37.75	36.80	36.40
Al_2O_3	9.61	2.42	0.38	0.50	0.64
FeO	tr.	tr.	1.24	3.52	4.05
Fe_2O_3	47.02	65.35	9.82	5.21	4.26
TiO_2	0.83	0.39	tr.	tr.	tr.
CaO	tr.	0.39	1.40	0.84	0.84
MgO	tr.	1.25	34.84	44.24	46.46
S	tr.	tr.	tr.	tr.	tre.
MnO	0.75	0.67	0.11	0.10	0.07
H_2O^-	1.10	1.20	3.78	0.22	0.39
H_2O^+	8.80	9.52	9.88	7.48	6.98
Cr_2O_3	4.20	8.40	9.28	0.35	0.23
Ni	0.46	1.11	0.37	0.31	0.28
Co	0.10	0.11	0.07	0.07	0.05
Total	**99.77**	**100.81**	**100.92**	**99.64**	**100.65**

D-4 (1.50-2.50 meter)	Coffee brown in colour, disintegrated and pisolitic type, soft and feebly magnetic laterite.
D-18 (24-25m)	Yellow ocherous laterite, very soft and feebly magnetic in nature.
D-32 (36-37m)	Gray to greenish brown in colour, weathered clayey material.
D-38 (42-43m)	Gray brown serpentinite with occasional specks of olivine.
D-44 (52-53m)	Light greenish serpentinised dunite.

[b] From the pit of Kansa.

	SN-1	SN-2	SN-2a
SiO_2	26.10	12.80	4.80
Al_2O_3	11.01	5.35	2.93
FeO	tr.	tr.	tr.
Fe_2O_3	50.60	65.83	74.81
TiO_2	0.94	0.72	0.56
CaO	0.17	0.18	1.14
MgO	0.43	0.26	0.18
S	tr.	tr.	tr.
MnO	0.64	0.80	0.68
H_2O^-	1.35	0.72	0.48
H_2O^+	7.12	10.00	11.48
Cr_2O_3	2.10	2.39	2.74
Ni	0.52	1.19	1.60
Co	0.08	0.07	0.08
Total	**101.06**	**100.31**	**100.48**

SN-1 (0-1 meter) Channel sample : Coffee brown in colour, moderately magnetic, disintegrated laterite.

SN-2 (3-4 meter) Channel sample : Brownish in colour, weakly magnetic, loosely consolidated laterite.

SN-2a (4-5 meter) Channel sample : Yellow ocherous laterite, extremely soft and light and feebly magnetic.

The typical lateritic nickel ore samples of Kansa as well as major chromite mines of TISCo and OMC have been analysed both for bulk and - 53µ fractions. This indicates enrichment of Ni in -53µ fraction with considerable decrease in silica. Presence of talc in fine range does not decrease silica content in Kansa sample.

The nickel and cobalt values of currently generating overburden samples of TISCo and OMC are evaluated in Table - 9. From these assay data, it is seen that nickel and cobalt values in the overburden sample of South Kaliapani mines are better than that of Sukinda chromite mines. This is also in conformity with the general observation that nickel & cobalt values show a decreasing trend from Kansa westwards to Bhimtangar.

Table - 9 : Assay values of some composite samples of Ni bearing overburden of TISCO and OMC mines. *

Sample details	% Ni	Co	Cr	Fe	Al_2O_3	SiO_2	LOI
1. SCM/COMP/QIX	0.72	0.06	2.93	26.10	3.95	46.03	7.01
1. SCM/COMP/QX	0.66	0.15	3.33	32.25	4.24	35.77	7.06
3. SKP/COMP/QD/HW	0.66	0.14	2.66	41.33	3.82	22.19	8.80
4. SKP/COMP/QD/FW	0.80	0.16	3.62	33.58	3.02	33.16	7.95
5. SKP/COMP/QF	0.71	0.24	4.48	18.61	4.10	57.38	4.90
6. SKP/COMP/QD-QF	0.65	0.12	4.41	38.29	7.08	21.03	9.07

*** Source IBM's report to RRL, Bhubaneswar, 1993.**

Some dumps at TISCO mines have been analysed and indicate 0.41-0.83% Ni and 0.05% Co.. Thus it can be concluded that overburden which are stacked in OMC and TISCO leasehold area will be having on an average 0.7 and 0.6 percent nickel values taking into consideration dilution caused during large scale mechanised mining operation.

Magnetite of fibrous habit, cherty, limonite, kaolinite rich limonite, nodular goethite and manganese oxide were analysed to know the element distribution and preference. This has been presented in Table-10.

Table - 10

Wt%	Martitised magnetite	Kaolin rich limonite	Cherty limonite	Nodular goethite	Mn-oxide mineral
Cr_2O_3	-	-	0.40	12.60	-
Fe_2O_3	94.27*	33.48	19.00	69.37	7.99
SiO_2	0.11	27.87	76.74	1.20	-
CaO	0.03	0.04	0.02	0.05	11.55
NiO	1.45	0.51	0.47	0.19	8.88
MnO	3.38	0.15	0.15	0.31	-
MnO_2	-	-	-	-	53.12
MgO	0.59	0.10	0.22		-
MgO	0.59	0.10	0.22		
Al_2O_3	-	20.00	0.32	-	-
LOI	tr.	18.33	2.18	11.55	17.62
Total	**99.83**	**100.48**	**99.50**	**98.87**	**99.16**

* Contains 0.85% FeO.

The low content of ferrous iron indicates total transformation of magnetite into martite under a strong oxidising condition in the weathering profile. Martite has further been oxidised to maghemite. However, Ni and Mn continue to remain in the lattice of the primary spinel. Presence of dispersed kaolinite/ chert or their veinlets reduced the nickel content in the profile.

In the nodular goethite, nickel content is pretty low. In the polycyclic lateritic environment iron from Ni-limonite gets dissolved and reprecipitated as nodular goethite of last generation where nickel escapes in the ground water.

The Mn-oxide sample is essentially lithiophorite with minor quantities of psilomelane and goethite. But there is preference of nickel and cobalt getting associated with this lithiophorite.

7. PROCESS OF MINERALISATION

The microscopic and chemical analysis of ultramafic rocks of Sukinda area reveal them to be absent in sulphide minerals. At the same time dunite-peridotite as well as the serpentinite samples have nickel content between 0.2 to 0.3 percent. Thus it is seen that nickel has not mobilised during serpentinisation stage, rather its concentration is related to the process of chemical weathering of partly serpentinised dunite-peridotite.

In subtropical environment in Sukinda in the presence of other favourable factors like gently sloping terrain, high rainfall, thick vegetation, slow percolation of meteoric water containing humic acid and CO_2, the principal constituents like magnesia and silica of the ultramafic bed rock along with calcium and alkali metals are removed in solution. The less mobile elements like Al, Cr, Fe, Mn, Ni and Co tended to lag behind and became residually concentrated. During the process of removal, a part of silica is redeposited as veins and thin band of chert and boxwork of cryptocrystalline silica within the lateritic nickel ore.

Mineralogical studies undertaken by various workers have not revealed any separate nickel bearing mineral in the nickeliferous laterites of the world, including that of Sukinda. High nickel values (>1%) in the zone of ocherous laterite in Sukinda area with abundance of goethite and virtual absence of magnesian silicates lends strength to the proposition that nickel is linked to goethite. But all these studies including even electron microprobe microanalysis could not give any clue to the exact nature of fixation of nickel in the goethite. Therefore, stress has been laid in recent studies on dissolution behaviour of nickel in various crystalline goethite matrices, such as nickel adsorbed with amorphous goethite and nickel lattice bound in goethite. To estimate the proportion of nickel in different modes, sequential leaching was conducted on - 53µ fraction of the bulk samples as goethite is essentially concentrated below this size to the exclusion of other gangue particularly silica.

Leachants are (i) 0.5µ oxalic acid, (ii) 0.1N H_2SO_4 and (iii) Conc. HCl. and leaching has been carried out for 3 hours in each case at boiling conditions. The % nickel extracted is given below.

	Extraction with		
Samples	**Oxalic acid**	**H_2SO_4**	**Conc. HCl**
TISCO	15	9	76
OMC	25	10	65
Kansa	37	12	51

In order to understand the effect of heating on nickel extraction, the - 53µ fraction were heat treated at different temperatures followed by leaching with H_2SO_4. The nickel extracted in solution is given below.

			(in %)
Temp. °C	**TISCo**	**OMC**	**Kansa**
120	8	12	22
250	43	55	71
350	61	70	88
% Fe in soln. at 350°C	56	63	85

From the sequential leaching and heating experiments it has been observed that TISCO overburden is more crystalline and lattice bound nickel is around 70%. Kansa Ore is more amenable to leaching as this is poorly crystalline and considerable amount of nickel is bound to goethite by way of physical adsorption.

8. PROCESSING OF SUKINDA NICKEL ORE

8.1 Beneficiation

In present commercial practice, lateritic ore containing a minimum of 1.2% Ni is used for nickel extraction. The lateritic/limonitic nickel ore of Sukinda is of a lower grade ranging between 0.6-1% Ni. Hence simple beneficiation to upgrade this ore is considered necessary.

Mineralogical and chemical analyses of Sukinda Ni limonite have established that nickel is associated with goethite, the main constituent of the ore. As goethite tends to concentrate in finer size fractions, upgrading of nickel can be achieved by separating the finer Ni-goethite from coarser fractions low in nickel, but contains mostly quartz (chert). However, admixtures of fine clay minerals like kaolinite, talc, weathered serpentine cannot be separated from goethite.

From the extensive beneficiation studies carried out at RRL, Bhubaneswar, best results have been achieved by washing, scrubbing, wet classification (sieving/hydrocyclone) for quartz rich low grade limonitic ores (0.5% Ni) to get a 1.1% Ni-concentrate. For clay and magnesia rich samples, flotation has to be supplemented using special collectors and depressants.

Therefore the process steps followed at RRL for beneficiation of overburden samples (0.6-0.7% Ni) collected from mechanised mining quarries of OMC & TISCO are as follows

i) Bulk ore is crushed, ground and wet classified (sieves for Ni rich OB, hydrocyclone for nickel poor sample) at 45μ size to obtain a nickel rich 1% finer fraction (70% Ni recovery)

ii) Low intensity magnetic separation of coarse (+45μ) fraction followed by gravity separation of magnetic fraction using Bartles-Mozley concentration yielding a chromite concentrate of 44% Cr_2O_3 (30% recovery). Recovery of Ni is increased by mixing magnetic fraction of +45μ with -45μ of the bulk.

iii) Froth flotation by sodium petroleum sulphonate at low p_H using Na-metasilicate as depressant. This gives a 1.2% Ni rich concentrate.

8.2 Metallurgical processing

For processing limonitic Ni-ore, there are two well established routes, viz, pressure leaching with dilute sulfuric acid at high temperatures and (ii) reduction roasting followed by ammoniacal ammonium carbonate (AAC) leaching. Even though the first process had the advantages of yielding high recoveries of both nickel and cobalt (90%), it produces an impure leach liquor. Besides, it involves operation at high pressure of about 45 atmosphere and high temperature 523 K (250°C). Moreover, there has not been any second plant based on the process. On the otherhand, there are many plants based on the second route. This process has the advantage of being operated at less stringent conditions and hence less capital intensive.

Process (ii) i.e. reduction roasting and AAC leaching as developed at RRL, Bhubaneswar consists of following steps, viz,

1. Reduction roasting in multiple hearth furnace with a suitable reducing agent.
2. Leaching nickel and cobalt values in the reduced mass with AAC solution under aeration / oxygenation.
3. Solid liquid separation to separate the leach liquor from the residue.
4. Separation of nickel and cobalt metal values by solvent extraction (SX) and electrowinning (EW) to get high quality nickel and cobalt metals, Cobalt metal can also be separated by precipitation as carbonate.

The recoveries of nickel and cobalt at various stages as obtained from laboratory studies are given in Table 11.

Table 11 : Recovery efficiencies of Ni and Co at different stages.

Stage	Scale	Metal Recovery (%)	
		Ni	Co
1. Reduction roasting Ammonia-Ammonium carbonate leaching	25 Kg/hr (Batch)	90	80
2. Solvent extraction	6 Lph	93%	93%
3. Electrowinning	(Continuous)	98%	98%

8.3 Possibility of Ferro-nickel production from the overburden

Either Kansa ore or the chromite mine overburden has nickel content of upto 1%, with Fe around 50%. This lean nickel ore is unsuitable for ferro-nickel production. But attempt has been made at RRL, Bhubaneswar to enrich the nickel content through prereduction followed by wet magnetic separation. An overburden sample of Sukinda valley containing around 0.87% Ni and 42% Fe was prereduced with solid fuel by pan sintering technique. The reduced mass was finely ground and concentrated by magnetic separator giving a product of 1.8% Ni and 50% Fe. Thus Fe : Ni in the feed was 48 and this came down to 28 in the concentrate. Further studies are in progress to improve the ratio and optimise the parameters.

9. USES

Nickel's ability to resist corrosion and to impart corrosion resistance, strength and specific physical properties to alloys leads to a great variety of applications, most important being in defence equipment, ship building, aerospace, aircraft, nuclear power plants, chemical and petroleum processing equipment, permanent magnets. The other uses include batteries, dyes and pigments, insecticides, electroplating, and in the form of stainless steel in utensils, kitchenware, hospital equipment, construction and several others. In short, nickel is a versatile, critical and strategic metal covering a wide range of defence, industrial and domestic applications.

10. TECHNO-ECONOMIC FEASIBILITY STUDY

There is no distinct nickel mineral in the lateritic nickel ores. Nickel is intimately associated with the fine grained ferrihydrite and goethite in three ways viz, (i) absorption, (ii) adsorption and (iii) lattice substitution. Studies on Sukinda ores reveal that nickel tends to enrich in the finer fraction below 45 microns.

Chromite mine overburden presents almost 80% of total nickel deposit in Sukinda valley and is available in plenty during chrome ore mining.

A metallurgical process to treat such overburden containing 0.6% nickel (representing one of the poorest grades of overburden) was developed based on benefication - reduction roasting - ammonia leaching - precipitation of basic nickel carbonate - solvent extraction - electrowinning. The major technological achievements of the process are (i) development of an unique benefication technique to upgrade the nickel content to 1.1% (ii) improvement of kinetics of leaching (iii) development of a solvent extraction process, which can be scaled up with Indian know-how (iv) development of an efficient nickel electrowinning process.

The process indicated 70% recovery of nickel during beneficiation, 80% during roasting and 93% during leaching and washing. Thus overall recovery of nickel upto solvent extraction stage is approximately 52%.

A techno-economic feasibility report has been prepared by MECON based on the above process for 10,000 tpa plant. In this process, Talcher coal will be utilised as the major source of energy. Further, if leach residue can be beneficiated to obtain 50% material as fine magnetite particles then the process will be cost effective as well as environmentally more attractive. To meet the country's requirement of nickel and cobalt from indigenous sources and to create conditions to permit continuation of opencast mining for chromite in harmony with environment, utilisation of nickelifeous limonitic overburden and nickel ore of Sukinda is of prime importance.

CONCLUDING REMARKS

A review of the chromite and nickel resources, mining and development scenario of the State points to certain definite action plan in the coming years, in the fields of exploration, mining, utilisation of low grade ores by beneficiation; recovery of nickel, cobalt and iron values from the overburden, dump management and environment management.

Exploration programme should keep in view the prospect of locating platinum group of elements, proving reserves of chrome ore below 100 m depth as well as along strike and determination of geotechnical parameters required for designing underground mining.

Although the indicated resources of chrome ore are adequate to meet the projected demand of the country for several decades, extraction and utilisation will necessitate underground mining and beneficiation.

Due priority should be given for indigenous production of nickel from the nickeliferous overburden of chromite mining in Sukinda sector.

Conscious efforts are called for to develop underground mining below 100 m depth in the friable ore zone in Sukinda sector.

In order that India can take a significant share in the export trade, the current grade, restriction for export of friable ore containing more than 52% Cr_2O_3 needs to be removed.

In nutshell, there is very good prospect and scope for integrated and sustainable development of the chromite and nickel ore resources of Sukinda valley on a long term basis with due regard to a sound and harmonius environment management measures.

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Coal

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1. INTRODUCTION

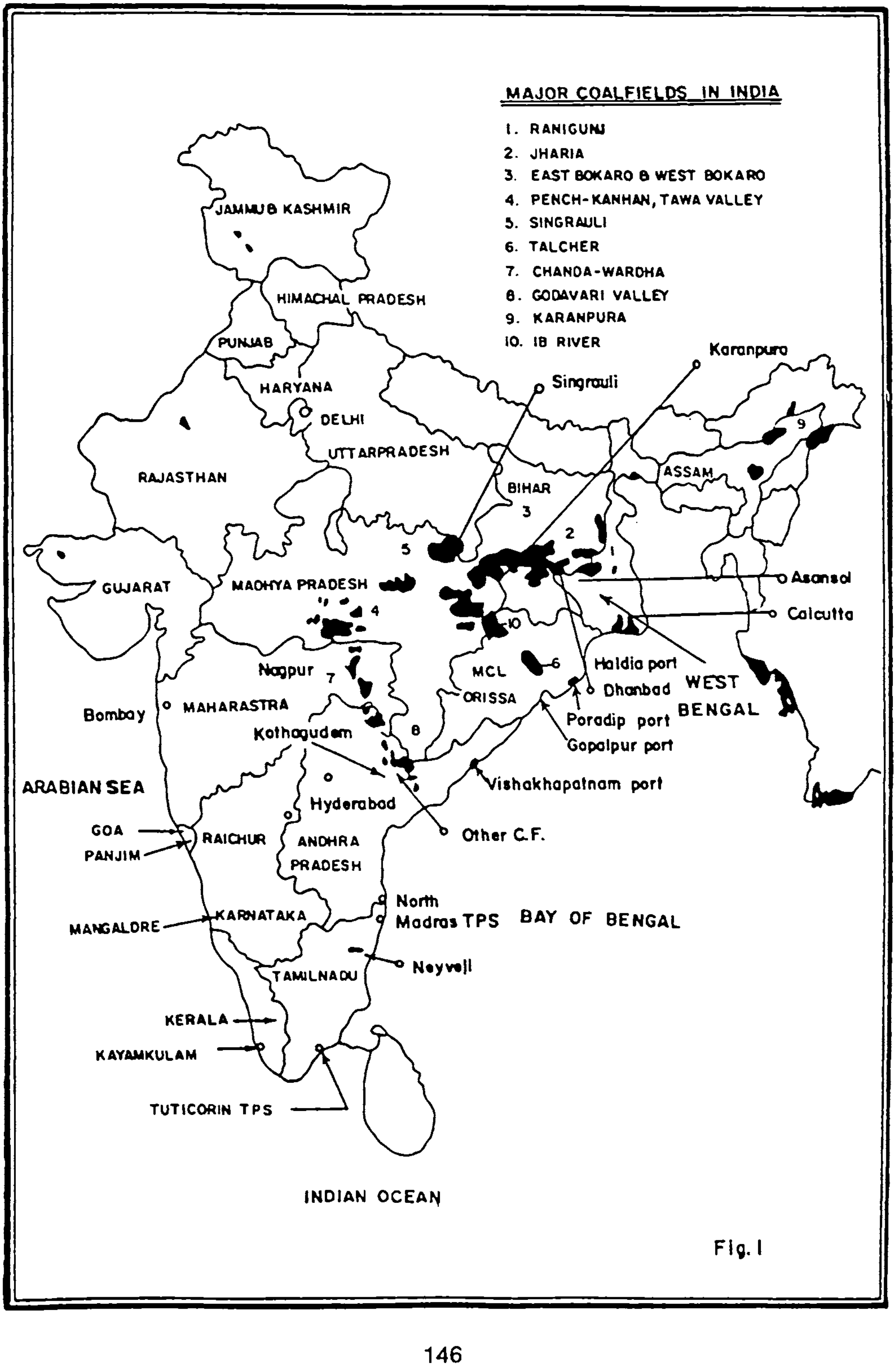
Out of 57 Gondwana and 14 Tertiary coalfields considered for the national inventory of coal, Orissa State has only two - in fact geologically only one and half - coalfields. Yet its share in the reserve so far established in the country amounts to 23.6%. In terms of spatial spread of prognosticated coal bearing area, the coalfields of the state of Orissa have about 7.6% area (2,723 sq. km). This goes to illustrate the high ratio of coal to non-coal strata in the two hitherto known coal bearing basins, viz. Ib River Coalfield and Talcher Coalfield and as a sequel to which these coal fields have an added advantage of being accorded most favoured coalfields status by the nature as far as quarriable potentiality is concerned. Historically the Talcher coalfield was discovered by Lt. Kittoe in 1839 and Ib River Coalfield by V. Ball in 1871 (Ref. 1,4) yet the real impetus for resource assessment by systematic exploration efforts was accorded only in the post nationalisation era of the coal industry since 1973. The importance of Orissa coalfields further enhances due to their vicinity to the east coast.

Besides bringing about changes in geological set-up and structural framework, recent geological investigations have indicated presence of sizable reserve of coal in hitherto unknown or uncertain areas. Occurrence of coal seams has been established along the western fringe and along the northern boundary of Talcher coalfield. A substantial quarriable reserve has been located in northern part of Ib - River coalfield (Gopalpur Area) and towards its south eastern extremity in Khinda - Talabira area. Thus the State is not yet saturated with coal discoveries and many more new finds cannot be ruled out.

2. LOCATION OF GONDWANA BASINS

Gondwana coals occur in India mainly along the three master Gondwana basins viz. Damodar - Koel Valley basin, Son-Mahanadi Valley basin and Godavari Valley basin. Coalfields of Orissa constitute the south-eastern part of the Son-Mahanadi Valley basin. Fig.1 shows the major coalfields of India.

The geographic locations of the two main coalfields of Orissa i.e. the Ib River coalfield and the Talcher coalfield is given in Table-1.


MAJOR COALFIELDS IN INDIA
1. RANIGUNJ
2. JHARIA
3. EAST BOKARO & WEST BOKARO
4. PENCH-KANHAN, TAWA VALLEY
5. SINGRAULI
6. TALCHER
7. CHANDA-WARDHA
8. GODAVARI VALLEY
9. KARANPURA
10. IB RIVER
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
DELHI
UTTARPRADESH
RAJASTHAN
GUJARAT
MADHYA PRADESH
BIHAR
ASSAM
WEST BENGAL
ORISSA
MCL
MAHARASTRA
ANDHRA PRADESH
KARNATAKA
TAMILNADU
KERALA
GOA
PANJIM
RAICHUR
MANGALORE
KAYAMKULAM
TUTICORIN TPS
Neyveli
North Madras TPS
Hyderabad
Kothagudem
Other C.F.
Nagpur
Bombay
Singrauli
Karanpura
Asansol
Calcutta
Haldia port
Dhanbad
Paradip port
Gopalpur port
Vishakhapatnam port
ARABIAN SEA
BAY OF BENGAL
INDIAN OCEAN
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2
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Fig. 1

FIG.2 GONDWANA BASINS OF ORISSA

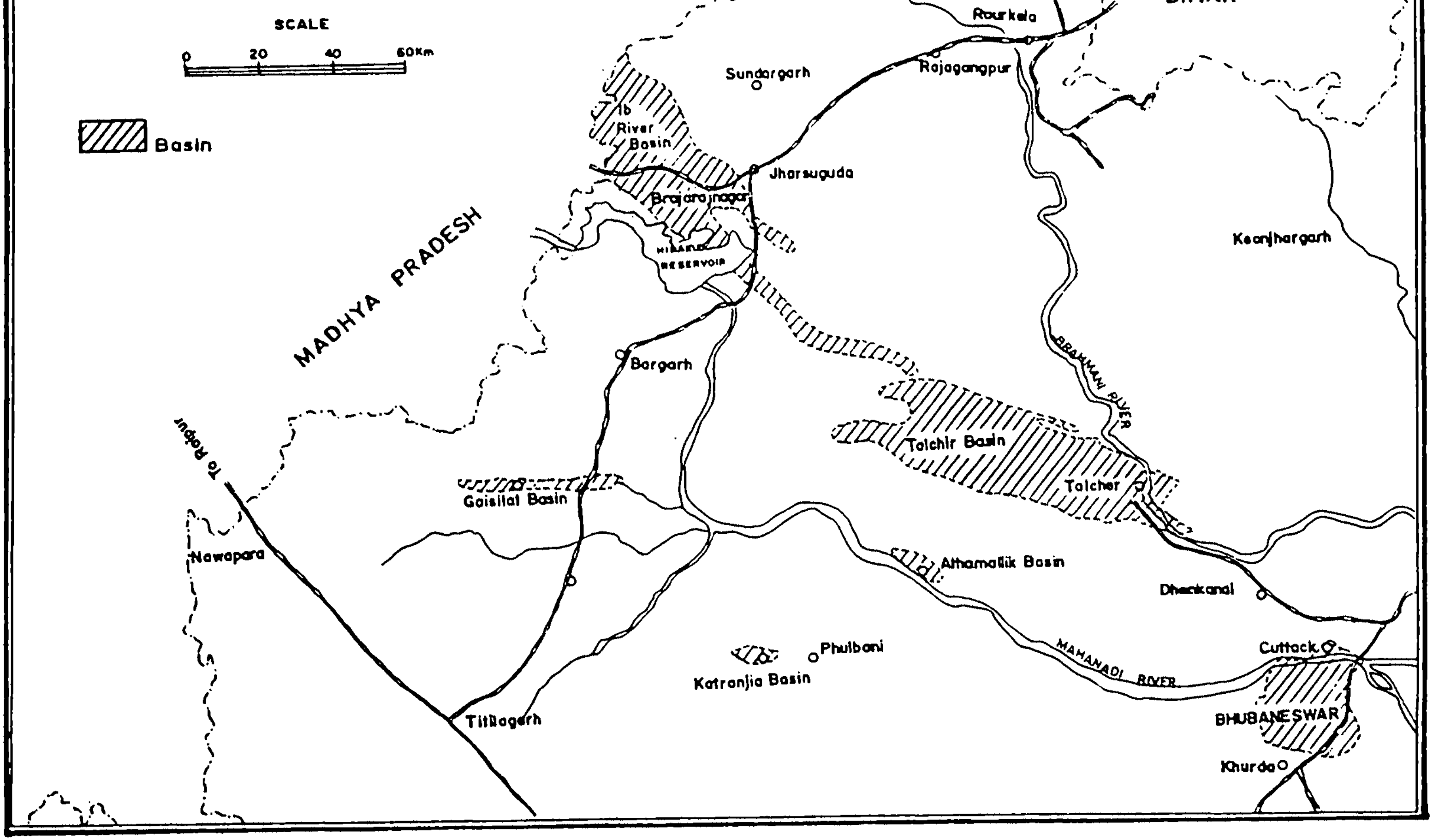

Table. 1 Location of major Orissa Coalfields.

Coalfield	Coordinates (+)		Basinal area Sq. km.	Districts
	Lat. N	Long E		
IB-River	21°31'-22°14'	83°32'-84°10'	1460*	Jharsuguda & Sundergarh
Talcher	20°50'-21°15'	84°09'-85°33'	1813	Dhenkanal, Angul & Sambalpur

* This includes 85 sq. km. area which has been added to the earlier known area of the coalfield on the basis of work carried out by one of the authors (Ref. 14).

In addition to above, there are four more Gondwana basins in Orissa:

1. Athgarh basin (800 sq. km)
2. Gaisilat basin (150 sq. km)
3. Athmallik basin (75 sq. km) and
4. Katranjia basin (75 sq. km)

Location of these basins are shown in Fig.2. Further, Pascoe (Ref. 4) has indicated a number of outliers around Sambalpur and Ib River Coalfield. "Of these outliers, none of which exceeds a square mile (2.5 sq. km) in area occur on or near Ib-river, about 10 miles (16 Km) northwest of Sambalpur". Another outlier "is found just south of the Mahandi (River) and opposite to the junction with Ib (River). Another (outlier) is met with about 40 miles (65 km) further south of the Paljor (River), a tributary of the Ong (River) and yet another on the Tel (River), about 80 miles (130 km) south of Sambalpur".

Recently two very small Lower Gondwana outliers (22°4'45" : 83°41'30") lying 1.5 km north of Talendih village (northern part of Ib-River Coalfield) have been located by CMPDI geologists (Ref. 15).

3. GEOLOGICAL SET UP

In the Gondwana sequence of coal basins of Orissa, the identification and delineation of the formational lithostratigraphy above the Barakar Formation is yet to be firmly established in all the major basins. The combined efforts of various organisations as well as research institutes have, however, firmly established the succession from Talchir to Barakar and to some extent the Barren Measures. The problem related to "Supra Barakar", which are generally grouped as Kamthi Group (?)/ Formation (Ref.1), remains to be solved. The tentative geological succession of Talcher and

Ib-river Coalfields are presented in Tables. 2 A and 2 B. The lithological and palaeobotanical details (Ref. 5) of the Talchir, Karharbari and Barakar Formations of Orissa coalfields are too well known to dwell upon. However, some discussions are necessary about the Barren Measures and Kamthi Formations.

3.1 The classification of strata above Barakar Formation in the Talcher Coalfield has undergone rather rapid modification. The Supra-Barakar strata was subdivided into Raniganj, Panchet and Mahadeva Formations in late sixties and early seventies (Ref. 1, pp 212). This has been revised.

Table. 2 A Geological Succession at Talcher Coalfield.

Age	Group	Formation	Lithology	Thickness (Metres)
UPPER PERMIAN TO TRIASSIC	LOWER GONDWANA	Supra Barakar/ Kamthi	Conglomerates, ferruginous sandstones, pale greenish sandstones with rare shales and pink clay.	+250
MIDDLE PERMIAN		Barren Measures	Coarse to medium grained greenish grey felspathic sandstones with shreds and lenses of chocolate coloured clay, micaceous silt stone, dark grey shale, carbonaceous shale, purple brown clay and clay ironstone	+317
LOWER PERMIAN		Barakar	Fine to coarse grained felspathic whitish sandstones, subordinate siltstone, grey shale, sandy shale, fireclays and basal polymictic conglomerate bed (2m to 47m) with coal seams	600
LOWER PERMIAN		Karharbari	Whitish arkosic sandstone carb-shales, grey shales and one coal seam and its splits	270
UPPER CARBONIFEROUS		Talchir	Rythmites greenish sand stone turbidites, olive coloured needle shales & diamictites, conglomerates etc. tilites & tilloids.	+170
——— Unconformity ———				
PRECAMBRIAN		Granites gneisses, amphibolites, migmatites quartzites and pegmatites etc.		

Table. 2 B

Geological Succession of Ib River Coalfield (Ref. 13 and 21)

Formation		Lithology	Thickness (Metres)
LOWER GONDWANA	Kamthi (Upper)	Pebbly sandstone, ferruginous sandstone & red shales.	+ 300
	Kamthi (Middle) =Raniganj	Fine grained sandstone, siltstone, coal seams.	
	Kamthi (Lower) = Barren Measures	Grey shales, carbonaceous shales, sandstone, clay and ironstone nodules.	About 200
	Barakar	Grey sandstone, carbonaceous shale, siltstone with thick coal seams and fireclay.	575
	Karharbari	Black carbonaceous sandstone, pebble bed, coal seams.	90-125
	Talchir	Diamictite, greenish sandstone olive and chocolate shales, rhythmites.	+130
		Non-conformity	
PRECAMBRIAN		Granite, gneisses, schists, etc.	

Considering lithological make up of rock pile it is considered more appropriate to designate it under one lithostratigraphic unit. The Kamthi Formation is in uniformity with the stratigraphy of other basins (of Gondwana) of Mahanadi Valley (Ref 2, p 43). However, recent studies by CMPDI (Ref. 12 & 13) and GSI (Ref. 16) have indicated that the lower part of Kamthi Formation has lithological characteristics similar to the Barren Measures. Earlier, entire western part of Talcher coalfield was believed to be covered by so-called supra-Barakar Formation. Investigation through drilling in the extreme western part of the coalfield in Rail area by DMG (O) (Ref. 17) has revealed that Barakar Formation containing numerous coal seams occur all along the western fringe (Fig. 3).

3.2 In Ib River Coalfield, Mukhopadhyay (Ref. 6) in his unpublished work has recognised Upper and Lower Kamthi Formations with a disconformity (?) between the two Formations. The Upper Kamthi Formation has two members separated again by a disconformity. He has also reported occurrence of P_2O_5 (from traces to 24%) in Kamthi Formation in Rohini block of the Ib River Coalfield. The lithostratigraphic set-up of these Kamthi lithounits appears to be very similar to those described by Pandey (Ref. 7) in the Wardha valley and Pranhita Godavari basins.

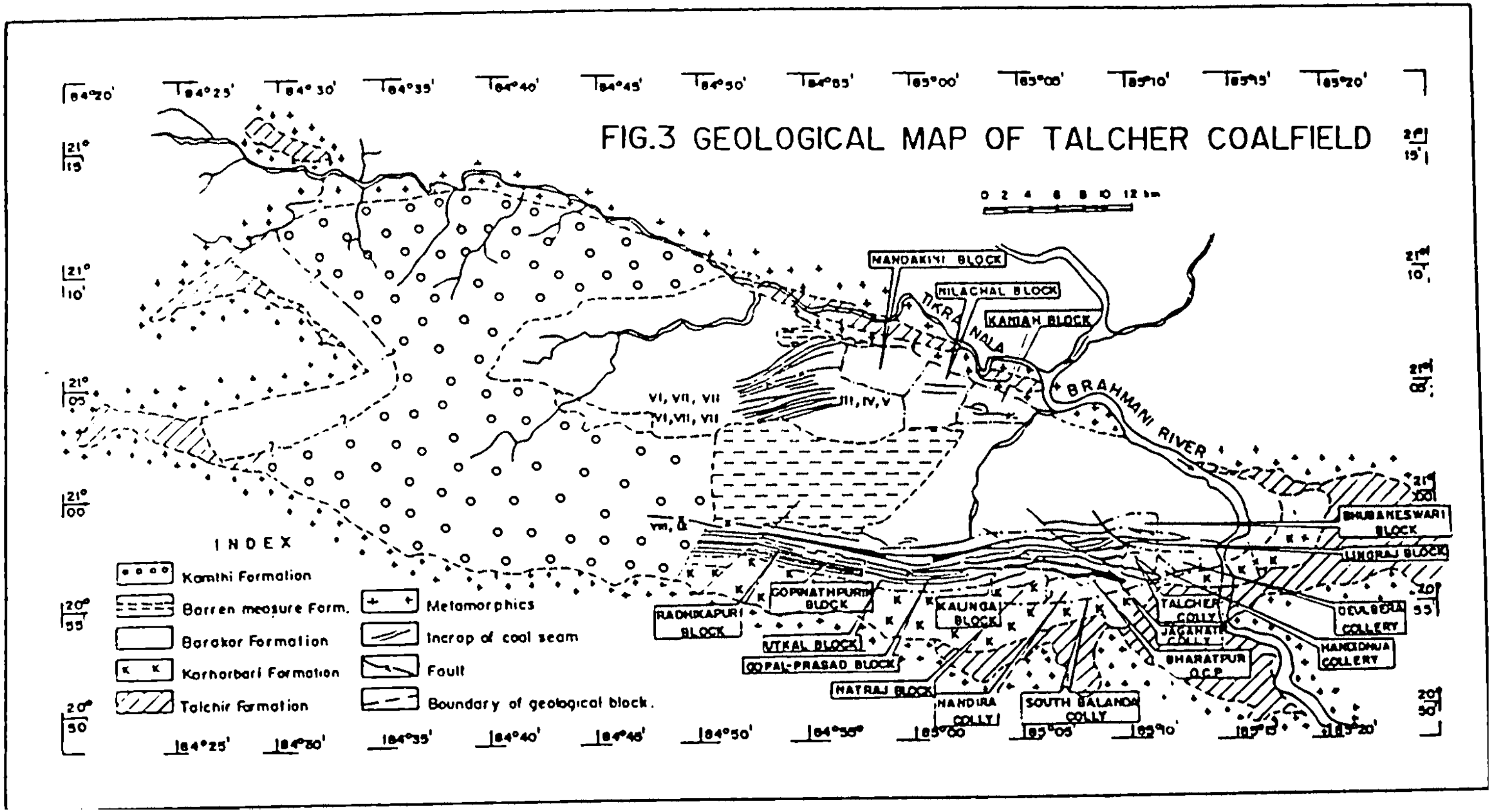

FIG.3 GEOLOGICAL MAP OF TALCHER COALFIELD

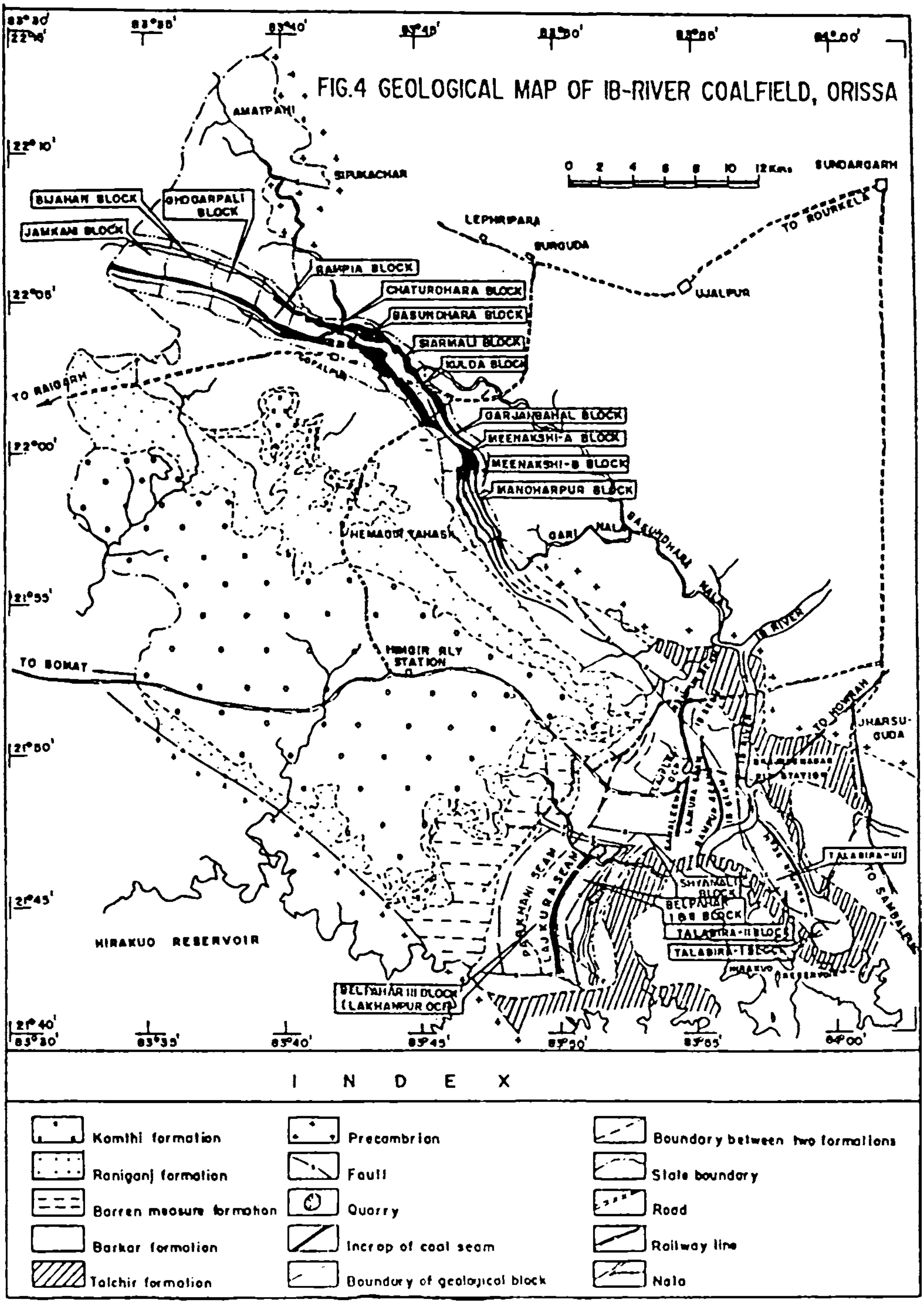

FIG.4 GEOLOGICAL MAP OF IB-RIVER COALFIELD, ORISSA

Regional investigation through drilling by GSI in the northern part of the Ib River coalfield (Ref. 21) has indicated that Kamthi Formation can be divided into three parts. The lower part has been correlated with Barren Measures and middle part with Raniganj Formation. The upper part has been retained as Kamthi Formation (Fig. 4). Raniganj Formation is reported to be coal -bearing.

The stratigraphic relationship of a thick tilloid boulder conglomerate (upto 25m. thick) vis-a-vis Rampur seam (25 to 60m), recently established in the Khinda-Talabira region in Ib River coalfield by DMG (O) is an interesting find (personal communication and field study). The Rampur seam is overlain by thick fireclay bed (4 to 8 m) which, in turn is overlain by thick boulder bed (Fig.-4). The individual boulder size of this bed usually varies from 35 cm to 10 cm. The occurrence has similarity with that of Seam-I of the Talcher coalfield, except that Seam-I belongs to Karharbari Formation and Rampur seam is considered to be of Barakar Formation. The boulder bed of Talcher coalfield, however, directly overlies Talchir shales in the northeast part of the Talcher coalfield near Shyamal block.

3.3 Athgarh Basin

The Athgarh basin over which Bhubaneswar city is located covers an approximate area of 800 sq. km. It is mainly covered by the rocks of Upper Gondwana Group and intruded by a single known basaltic dyke near the Sidheshwar hill. The lowest exposed section consists of coarse, loose textured conglomerate and ferruginous sandstones while light coloured clays and sandstones occur towards top (Talbasta clays). This top sequence is perhaps co-eval of Dubrajpur sandstones of Rajmahal coalfield. The reported occurrence of coaly substance and carbonaceous shales in Athgarh basin points out towards the possibility of overlap of the rocks of Lower Gondwana Group by the Upper Gondwana Group. Thus, the Athgarh basin needs a very detailed study, keeping in view that the Kamthi overlaps on the Barakar Formation in the Wardha valley coalfield. There is a considerable gap in the overall knowledge of this basin which in spatial extent compares with numerous Damodar valley coalfields, like Ramgarh, South Karanpura, Auranga, Hutar, Daltonganj etc.

3.4 Gaisilat Basin

Elongated in an east-west direction and lying between Bargarh (45 km) and Bolangir (30 km), the Gaisilat basin comprises of Talchir and Karharbari/ basal Barakar Formations. Information obtained from a few boreholes drilled by DMG (O) indicate occurrence of thin coal seams (<1m thick) which have not been considered encouraging. However, further exploration is desirable to assess its economic viability.

3.5 Katranjia and Athamallik Basins

Katranjia basin is located at about 15km. west and Athmallik basin at about 40 km. northeast of Phulbani town. These are small Lower Gondwana outliers. Investigations carried out have not indicated encouraging results.

4. STRUCTURAL FRAMEWORK

An outline of the geological structure of the two main coalfields is given herewith.

4.1 Talcher Coalfield

In major parts of the Talcher Coalfield covered by the Barakar/ Karharbari/Talchir exposures, the strike of beds is east-west except to the east across Brahmani river where basinal closure is evident by swinging strike with westerly plunge, The coalfield is characterized by the east-west running strike faults and in the process, repetition of coal seam incrops has improved quarriable potentiality in general. Either rigid northern boundary or the basement high in Kaniha block (Ref. 22) has resulted in formation of a structural high as reflected by a local easterly plunging anticline. Structural set up of the western part of the coalfield beyond Kosala - Chendipada is virtually unknown or at best is extremely tentative except along the western extremity where attitude of strata is anticlinal with an easterly plunge due to presence of metamorphic high. Thus, basinal structure of Talchir coalfield appears to be preserved on three sides except north (Fig.-2). The northern boundary of the Talcher coalfield is traversed by numerous east-west trending faults. Though dips are usually shallow, in the coalfield, steeper gradients have been encountered near faults.

4.2 Ib-River Coalfield

The Ib River Coalfield shows westerly plunging synclinal flexure which is like a half elliptical basin closed towards southeast and open towards northwest having an axial trend in NW-SE direction. In the northwest it forms a continuous basin with the Mand-Raigarh Coalfield. The south-western boundary of the basin is marked by a boundary fault juxtaposing Barren Measures and Raniganj Formations against Precambrians. The Khinda-Talabira area is a sub-basinal extension of main Ib-River basin to the south-east, where rocks of only Lower Barakar Formation and those of basal Lower Gondwana Formation are preserved.

Geological mapping of underground mines (Ref. 18) and opencast mine (Ref. 19) indicate that the coalfield is structurally much less disturbed than expected earlier.

5. IGNEOUS ACTIVITY

Till recently both the coalfields were considered to be free from igneous activity and resultant devolatilisation of coal in spite of high geothermic gradient recorded in the Gopalprasad (West) block. Natural burning along the incrop of the coal seam has been noticed for the first time in Ib River coalfield by CMPDI geologists in Chaturdhara Block (Ref. 15) and subsequently in adjoining area. Petrographic and X-ray studies on burnt samples of borehole core from Kulda block (Ref. 20) has indicated that burning may be due to volcanic activities but it is yet to be established as it has not been corroborated by surface evidences gathered during geological mapping.

6. SEQUENCE OF COAL SEAMS

The major coal bearing formations in both the coalfields are Karharbari and Barakar, though occurrence of coal seams in Raniganj formation has been reported by GSI in Ib River coalfield. Based on the status of present knowledge of surface and sub-surface data there appears to be one coal seam in Karharbari Formation in both coalfields and 12 and 4 coal seams in Barakar Formation in the Talcher (Ref. 23,25) and Ib River coalfields respectively. By and large, the lower seams are thick in eastern part and split to the west in both the coalfields. The Seam-I of Talcher is thin in east (2 to 4 m) and thickens to about 15-20 m in east-central part and again thins to west and deteriorates to carbonaceous shale. Younger seams coalesce in the west near Utkal block to give extremely favourable coal to non-coal ratio in vertical litho-column but the seams are highly interbanded. Based on the exploratory drilling carried out by various agencies in these two coalfields, the broad succession of coal seams built-up by the CMPDI is given in Tables. 3 A and B.

Table. 3 A Succession of Coal Seams, IB-river Coalfield.

Seam/Coal horizon	Thickness range (m)	Remarks
BARAKAR		
Belpahar coal horizon	24-30	Highly interbanded coal section. In two sections in northern part
Parting	105-195	Generally considered as uneconomic
Parkhani coally horizon	0.5-1.0	Mostly shaly coal and carb. shale.
Parting	92-120	
Lajkura seam	15-89	A persistent and highly banded horizon, splits in 4 sections.
Parting	16-112	
Rampur coal horizon	27-80	Highly interbanded, contains 5 to 6 sections.
Parting	3-55	
KARHARBARI		
IB Seam	2-10	Impersistent in northern part, splits up in 3 sections.

Table. 3 B Succession of Coal Seams, Talcher Coalfield.

Seam/Coal horizon	Thickness range (m)	Remarks
BARAKAR		
Seam XIII	4-5	
Parting	6-13	
Seam XII	1-4	
Parting	5-22	
Seam XI	2-12	
Parting	2-6	
Seam X	2-7	
Parting	6-23	
Seam IX	4-30	
Parting	5-20	
Seam VIII	5-15	
Parting	1-8	Coal seams tend to merge into a single coal horizon near Utkal block due to reduction in parting. Overall thickness of the coally horizon varies from 70 to 110 metres.
Seam VII	3-8	
Parting	5-15	
Seam VI	2-5	
Parting	10-23	
Seam V	2-5	
Parting	3-15	
Seam IV	2-25	
Parting	10-25	
Seam III	7-30	
Parting	3-35	
Seam II	15-40	
Parting	120-130	
KARHARBARI		
Seam-I	3-20	In three splits of 1 to 12m thickness.

7.0 QUALITY OF COAL SEAMS

Though the State of Orissa is endowed with considerable reserves of coal, yet qualitatively they cannot be equated with coals of the Damodar Valley coalfields. The coals of Ib-River and Talcher coalfields are high moisture (5.2% to 8.4%), by and large highly interbanded and high in inherent ash contents. Only Ib-seam and Seam-I in Ib-River and Talcher coalfields respectively could be considered as low ash from Indian standards. All the coals are non-coking. In Gopalprasad (West), Talcher coalfield, possibility of reduction of volatiles and moisture contents exists due to high geothermal gradient. The broad quality parameters and characteristics of the coal seams of Orissa are given in Tables. 4A, 4B and 4C.

Table. 4A

Broad Quality Parameters of Coal Seams, Ib River and Talchir C.F.
Proximate Analysis on equilibrated basis.
In band (upto 1 m and excluding obvious dirt bands).

Ib-River Coalfield					Talcher Coalfield				
Seam/ Horizon	**M%**	**Ash%**	**VM%**	**Gross C.V. K. Cal/kg grade**	**Seam Horizon**	**M%**	**Ash%**	**VM%**	**Gross C.V. K. Cal/kg grade**
Belpahar	5.7 7.2	42.2 52.9		- G to non vendable	IX	5.2 6.4	43.0 46.4	24.0	3357-3773 E-G
Parkhani	6.6 8.4	35.1 48.1		- F-G	VIII	6.2 6.9	40.7 44.7	24.8 26.1	3451-3750 G
Lajkura	5.6 7.8	32.0 45.1	23.0 (One only)	3280-5285 E-G	VII	5.7 7.3	38.2 44.7	24.9 26.6	3530-4020 F-G
Rampur	4.2 7.6	19.4 50.0	19.1 - 27.8	2390-4640 C-G	VI	5.4 7.5	37.7 51.0	23.1	3145-3908 F-G
Ib	6.1 7.5	18.6 31.1		4630 C-E	V	5.8 8.4	29.6 43.2	23.9 28.3	3644-4584 E-G
					IV	4.4 5.9	35.2 45.2	25.2 27.6	3447-4258 F-G
					III	5.5 8.2	30.0 41.4	26.5 29.5	3669-4616 E-G
					II	5.5 7.7	31.8 48.9	24.4 31.5	3597-4848 F-G
					I (Top)	5.0 7.6	13.0 36.0	26.7* 40.0	5730-6235 B-F
					I (Middle)	5.0 7.0	10.0 37.0	27.0* 36.0*	5770-6280 A-F
					I (Bottom)	4.5 8.0	12.0 48.2	25.4* 30.6	4450-5950 B-G

(*) On ex-band basis. Values on including dirt bands upto 1m but excluding all obvious dirt bands of 5 cm and above thickness.

Table. 4B HGI & Ash Fusion (Including Bands)

	Ib River Coalfield					Talcher Coalfield			
Seam	HGI	IDT°C	HT°C	FT°C	Seam	HGI	IDT°C	HT°C	FT°C
Belpahar	N/A	N/A	N/A	N/A	IX	52-56	1040-1200	1380-1450	1400-1450
Parkhani					VIII	57-58	1040-1210	1390-1450	1400-1450
Lajkura	56-63	1190	1400	1400	VII	51-59	1140-1200	1380-1400	>1400
					VI	55-65	1120-1200	1400 or more	1,380 or more
					V	51-58	1080-1230	1400 or more	1,400 or more
Rampur	69	1180-1210	1400	1400	IV	57-61	1130-1220	1390-1450	1400 or more
					III	45-63	1060-1230	1400-1450	1400-1450
					II	48-70	1060-1250	1400-more	1400 or more
Ib	60-83	1190-1220	1400	1400	I Top	N/A	1050-1200	1360-1400	>1400 or more
					I Middle	N/A	1050-1180	1410-1450	>1450
					I Bottom	N/A	1080	1350	1400

Notes : -
1. On ex-band basis
2. Data of Talchir based on GRs of Kalinga, Utkal and working mines and include sectional data also.

Table. 4C Ash Analysis

Coalfield	Seam	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	MnO %	P_2O_5 %	SO_3 %	CaO %	MgO %	Alkali + Errors %
1	2	3	4	5	6	7	8	9	10	11	12
Ib-River	Belpahar										
	Parkhani										
	Lajkura										
		58.53-	24.13	4.78-9.52	1.22-		0.04-	0.04-	1.10-	1.13-	1.32-
		60.28	28.34		2.20		0.78	0.86	1.84	1.36	1.55
	Rampur										
		52.46	24.03	17.80	1.38	0.18	0.04	0.49	0.98	1.10	1.54
	Ib										
		56.52	26.58	12.42	1.60	0.12	0.05	0.40	0.83	1.39	0.09
Talcher	IX*	59.60	29.62	4.36	1.70		0.51	0.26	1.46	0.56	1.93
	VIII*	59.30	29.66	4.28	1.80		0.63	0.30	1.64	0.61	1.78
	VII*	59.96	29.76	4.42	1.69		0.61	0.23	1.72	0.65	0.96
	VI*	60.20-	29.10-	4.18-	1.69-		0.58-	0.20-	1.61-	0.62-	0.83-
		60.42	29.84	4.42	1.72		0.61	0.23	1.72	0.65	0.96
	V*	60.83-	30.06-	3.82-	1.60-		0.49-	0.22	1.28-	0.46-	0.60-
		61.10	30.26	3.84	1.65		0.52		1.47	0.61	0.80
	IV	60.80	29.60	4.8	1.40		0.60	0.30	1.50	0.60	0.40
	III*	59.86-	29.12-	3.88-	1.62-		0.62-	0.24-	1.69-	0.64-	1.27-
		60.21	29.94	4.80	1.71		0.69	0.29	1.82	0.82	1.33
	II	57.6-	29.6-	4.2-	1.6-	0.04	0.61-	0.2-	1.5-	0.5-	0.3-
		60.7	30.0	4.4	1.75		0.8	0.3	1.8	1.63	0.7
	I Top*	66.44	21.21	7.63	1.50	0.11	0.06	0.71	0.92	1.47	1.95
	I Middle*	56.68-	24.43-	7.63-	1.38-	0.10-	0.10-		0.91-	1.44-	1.49-
		61.46	25.53	9.38	1.54	0.17	0.11		1.36	1.70	2.66
	I Bottom*	58.0-	24.6-	8.47-	1.34-	0.11-	0.09-	0.67-	1.11-	1.32-	0.65-
		61.3	25.35	10.25	1.61	0.18	1.11	1.03	1.18	1.59	1.04

Notes :- 1. * on ex-band basis

2. Data of Talchir based on GRs of Kalinga and Working mines.

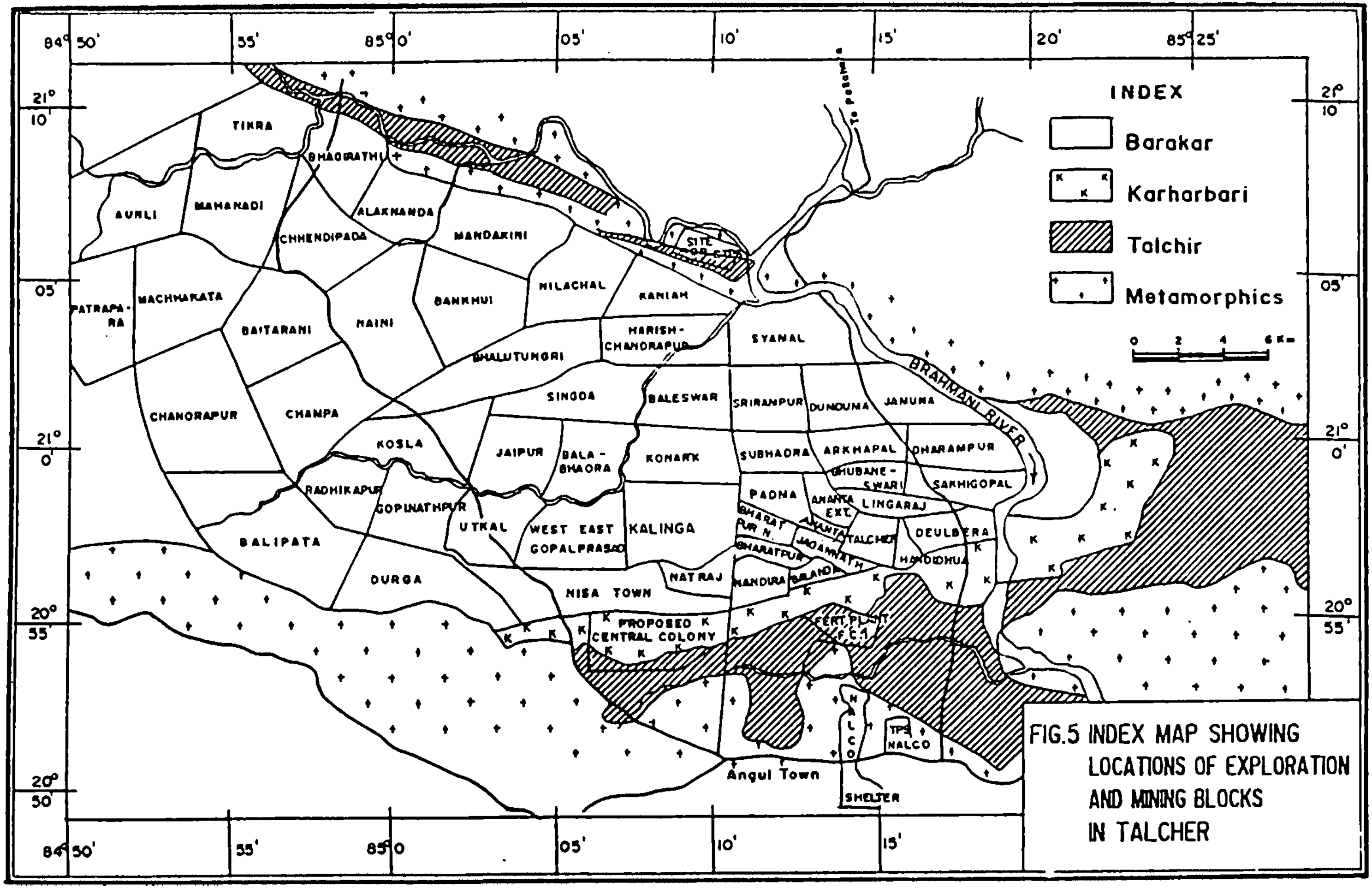

FIG.5 INDEX MAP SHOWING LOCATIONS OF EXPLORATION AND MINING BLOCKS IN TALCHER

8. STATUS OF EXPLORATION

The earliest record of exploration in the Talchir C.F. dates back to 1875 when PWD Department of Government of Orissa sank six shafts in the Gopalprasad area to obtain 80 tonnes of coal sample. In recent past, the Indian Bureau of Mines and National Coal Development Corporation, a forerunner of CMPDI, carried out detailed exploration in the eastern part of Talcher C.F. in late fifties. GSI entered this coalfield for regional exploration in 1963 and are continuing their endeavours to enhance reserves. The detailed exploration in the coalfield is being carried out by CMPDI and DMG (O). MEC is engaged in promotional drilling in the western part. The exploration and mining blocks in Talcher CF are shown in Fig.5.

In the Ib-River coalfield, the drilling operation was initiated in 1884-86 by W. King. However, regional exploration by GSI has been started only from 1964-65. The DMG (O) are engaged in detailed exploration in this coalfield on behalf of CMPDI since 1974-75. Currently (March ' 95) 6 drills of CMPDI & DMG (O) are engaged in detailed exploration in this coalfield apart from 2 drills of the Geological Survey of India for regional exploration. Thus, at present 20 drills are working in the coalfields of Orissa.

In order to evaluate the status of exploration in these coalfields, statistical data pertaining to -

- the basinal area including Talchir Formation,
- prognosticated coal bearing areas excluding lower barren lithounits,
- deep-seated coal deposits below the Upper Gondwana/ Kamthi, and
- the areas for which sub-surface data and geology is not well established,

have been calculated to demarcate the potential areas for coal exploration. The status of the regional and the detailed exploration in these potential areas have been determined to evaluate the future strategy of coal exploration in the State of Orissa. These data are presented in Table. 5.

Table. 5

Status of Regional and Detailed Exploration in Ib-river and Talcher Coalfields (As on 31.3.94)

Sl. No.	Item	Ib-River Coalfield	Talcher Coalfield	Remarks
		(Area in square km.)		
1.	Basinal Area	1460	1813	
2.	Prognosticated coal bearing area	1140	1583	
3.	Area excluded presently for detailed exploration			
	a) Deep seated	93		Beyond 600m generally
	b) Unknown geology	126 +85*	283**	* added by CMPDI ** Depth of coal -seam beyond 300m
	Sub-Total :	**219+85***	**283****	
4.	Potential area for exploration	836	1300	
5.	Coverage by Regional Exploration			
	a) Upto 300m depth	197	274***	(***) Including Sakhigopal block where semi-detailed work has been done.
	b) Beyond 300m depth	59	44	
	Sub-Total :	**256**	**318*****	
6.	Remaining area to be covered by Detailed Exploration			
	a) Upto 300m depth	70	128	
	b) Beyond 300m depth	517	729	
	Sub-total :	**587**	**857**	
7.	Detailed Exploration completed, mainly upto 300m	103	131	
8.	Area to be taken up in subsequent plan periods	240	275	

Thus, it would be seen from the above table that out of 836sq.km. of potential area for exploration, little over 103 sq. km. (about 12%) area has been covered in the Ib-River coalfield.

Similarly, about 10% (131 sq.km) area, out of 1300 sq.km. potentially delineated for exploration has been covered in the Talcher coalfield.

9. RESERVE

The reserves estimated pertain to the areas explored so far on regional basis or in detail. No estimation of "Total Reserves" has been done nor the prognostication has been attempted. The reserves as estimated by CMPDI and GSI have been given in Table. 6. Orissa contains 46,527 million tonnes of coal out of the total reserve of 196, 892 million tonnes of coal occurring in India as estimated on 1.1.1994

Table - 6

Category-wise, Depth-wise reserve of coal in Orissa as on 1.1.1994 (For seams 0.9m and above in thickness).

(Reserves in million tonnes)

Name of the Coalfield	Depth (In m.)	Proved	Indicated	Inferred	Total
IB-RIVER					
Coalfield	0-300	1754.39	7251.20	4002.63	13008.22
	300-600		2981.60	5051.67	8033.27
Total	**0-600**	**1754.39**	**10232.80**	**9054.30**	**21041.49**
TALCHER					
Coalfield	0-300	4907.05	10376.04	6826.52	22109.61
	300-600		1666.63	1672.27	3338.90
	600-1200		36.67		36.67
Total	0-1200	4907.05	12079.34	8498.79	25485.18
Grand Total	**0-1200**	**6661.44**	**22312.14**	**17553.09**	**46526.67**

As stated earlier, Talcher and Ib-River Coalfields have only non-coking coals. Analysis of grade-wise reserves indicate that superior grade coal (Grades A,B.C and D) constitute only about 10% of the total reserves. The rest is power grade coal. The break up is shown in Table. 7

The mineable and recoverable reserves of the Orissa Coalfields have been evaluated broadly by Sub-Group-II of Working Group for Coal & Lignite, VIIIth Plan. While arriving at these reserves, following assumptions have been made. :

Seams having thickness below 1.2m cannot be mined with present techno-economics and hence their entire in situ reserves have been excluded.

At present reserves upto 600m depth may be considered as economic and reserves lying beyond this depth may be considered as "marginal reserves" to be excluded from present reckoning of mineable reserves.

Reserves blocked out under HFL, roads, railway lines, townships etc. have been excluded. Based on above factors mineable reserves have been arrived at.

Based on the project reports for mining, separate calculations have been made for " recovery factors" for underground and opencast projects to arrive at an overall recovery factor for the coalfield. This has been applied to arrive at "recoverable reserves" as given in Table 8.

Table. 7 Proved and Indicated Grade-wise breakup of Reserves (in million tonnes)

Grade	Talcher	Ib River	Total	% of Total
A	54.30	10.43	64.73	0.22
B	213.76	94.11	307.87	1.06
C	340.03	218.11	558.14	1.93
D	683.74	1,440.78	2124.52	7.33
E,F&G	15,694.51	10,223.78	25,918.29	89.46
Total	**16,986.34**	**11,987.21**	**28,973.55**	**100.00**

Table. 8 Approximate Mineable and Recoverable reserves. Ib-river and Talcher Coalfield, Orissa State

(Reserves in million tonnes)

Coalfield	Total Reserves	Reserves in seams below 1.2m thickness	All reserves below 600m depth	Blocked out reserves	Mineable Reserves	Recovery factor %	Recoverable reserves
Ib River Coalfield	21,042	12	-	540	20,490	42	8,606
Talchier Coalfield	25,485	161	37	578	24,709	57	14,084
Grand Total	46,527	173	37	1118	45,199		22,690

Note : The recovery factors computed pertain to 1989 when the total estimated reserves of coal in Ib River and Talcher CFs were respectively of the order of 18,702 million tonnes and 22,855 million tonnes. With the addition of about 5,000 million tonnes to the reserves during 1989-93 mostly amenable to opencast mining, the quantity of recoverable reserves would be higher.

10. MINING AND PRODUCTION

At present, 21 mines (10 underground and 11 opencast) are in operation. A number of new projects are in different stages of implementation. The total production during 1993-94 amounted to 24.30 million tonnes, of which opencast mines contributed 22.32 million tonnes. The break-up of production between Talcher and Ib-River coalfields was in the proportion of 15.50 million tonnes and 8.77 million tonnes which included 1.29 million tonnes and 1.40 million tonnes of superior grade non-coking coal. Coal produced in Orissa constituted approximately 10% of the country's production during 1993-94.

Open-cast mines use either shovel-dumper combination as in Bharatpur, Jagannath etc. or dragline-electric shovel-dumper as in South Balanda OCP etc. Underground mines are being worked/depillared by Bord and Pillar method with caving/stowing. Longwall method of mining is yet to be adopted in coal mines of Orissa.

About 85% of the total coal produced in Orissa is consumed for power generation. The other consumers include manufactures of cement, fertilisers and sponge iron. The existing modes of transport are rail, rail-cum-sea, MGR, road and belt conveyor.

Both Talcher and Ib-River coalfields have tremendous potential for large scale production on account of occurrence of thick seams at comparatively shallow depths and low dip resulting in low coal : overburden ratio thereby making it favourable for opencast mining.

Production pattern projected from the two coalfields is as follows

(in million tonnes)

	Talcher CF	Ib River CF	Total
1994-95	15.80	9.20	25.00
2001-2002	39.69 (1.29)	22.91 (1.40)	62.60 (2.69)

(Figures within brackets indicate the projected production of superior grade coal)

It may be seen that production of superior grade coal in 2001-02 is projected to remain at the same level as during 1993-94.

With growth in demand, Talcher and Ib River coalfields are capable of producing 50 million tonnes and 35 million tonnes per annum respectively in 10 years from now i.e. around 2006-07.

Achievement of the projected production will however depend on development of railway system including strengthening of the existing tracks and laying of new lines and other infrastructure facilities.

11. CONCLUDING REMARKS

The State of Orissa has 46.5 billion tonnes of coal which constitute about 23% of the total coal resources of the country. This reserve has been estimated within about 30% of the prognosticated coal bearing area of Talcher and Ib-River coalfields. Further exploration efforts are likely to increase the total reserve of coal in the State substantially.

Geological knowledge about other Gondwana basins, particularly Athgarh basin, is inadequate and needs further investigation.

In order to evaluate lithological, sedimentological, palaeobotanical and tectonic framework of the Gondwana coalfields of the State, a systematic project under S & T scheme should be formulated and implemented with the active collaboration of the Research Institutes, State Government, CMPDI & GSI. This would help to locate new areas of coal deposits hitherto not recorded.

The recent discovery of phosphorite beds in Rohini Block by GSI needs to be followed up by detailed exploration and to determine the regional limit of occurrences of these phosphatic beds in Ib-River as well as Talcher and Athgarh basins.

Occurrence of superior grade coal in Orissa is not much (2154 m.t.) But power grade coal occurs in plenty with favourable geological conditions.

Current level of production in the State is 24.30 million tonnes. Although, a production of 62.60 million tonnes is projected around 2001-02, the resource position will permit an annual production of more than 100 million tonnes.

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The views expressed, particularly about production prognostication, are those of the authors and not necessarily of the CMPDI/CIL.

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Dimension and Decorative Stones

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1. INTRODUCTION

Natural stones of different hues and shapes because of easy availability, incombustibility, thermal and electrical non-conductivity, ease of maintenance, aesthetic appeal and total functionalism have found widespread use as building materials in rural constructions and in modern architecture.

Any natural stone irrespective of composition and origin which can be cut, sized and shaped to suit the fancy and specifications of the builders, designers and architects are marketed as Dimension stones.

The commercial terminology of the dimension stones differ from that of the petrographic one. The various rocks which are quarried as Dimension stones include granite, marble, sandstone, limestone, slate, laterite and khondalite.

Although marble, sandstone, khondalite, slate, limestone and laterite mean the same in geological and trade parlance, Granite means quite a lot. It includes a wide variety of rocks ranging from acidic to ultramafic, which meet the requirements of Dimension stone.

The rocks which are included under the broad category of Granite are dolerite, gabbro, charnockite, syenite, granulite, leptynite, anorthosite, gneisses besides the typical light coloured acid igneous granular rock composed of quartz and felspar, with minor amounts of mica and ferro magnesian minerals.

2. DESCRIPTION AND PROPERTIES OF STONES

The description of stones or rocks given here is in the context of their utilisation as dimension stones.

Granite

The suitability of granites for utilisation as dimension stones depends to a large extent on their physical, chemical and mineralogical properties. These are discussed.

The range of some of the important physical properties of different varieties of granite is as follows;

Hardness (Moh's scale)	5	-	6.5
Specific gravity	2.6	-	3.2
Compressive strength (Kg/cm²)	1000	-	3000
Tensile strength (Kg/cm²)	70	-	300
Porosity (%)	0.1	-	1

The mineralogy of the constituents of granite plays an important role in determining the suitability of the rocks for use as dimension stones. Sulphide minerals rust rapidly and cause objectionable stains. Garnets are generally susceptible to weathering / alteration leaving small voids. Flaky minerals like biotite create problem during polishing as they come out leaving small voids. Presence of clay minerals like kaolinite and sericite adversely affect the polishing characteristics. Harder minerals like corundum and garnet offer resistance to polishing and increase the polishing cost.

The dimension stones under the 'Granite' category can be broadly divided into two types viz. acidic and basic rocks. The acidic rocks consist mainly of quartz, orthoclase, perthite, plagioclase and garnet with or without subordinate amounts of microcline, myrmekite, biotite, sericite, muscovite etc. Traces of chlorite, zircon, apatite, sphene and carbonates are also present. The basic rocks on the otherhand consist dominantly of clino-pyroxene and plagioclase with minor amounts of orthoclase, amphibole, chlorite, orthopyroxene and opaque minerals. Besides the desirable physical and mineralogical properties other characteristics which determine the suitability of a rock for use as dimension stones include the following :

(a) Colour consistency is an important criteria for dimension stones. If the variation of colour of the rock is not within an acceptable range, the deposit may lose its value as dimension stone.

(b) The recent developments in the processing technology necessitates quarrying of bigger blocks . The quarrying of big blocks is impeded if the deposit contains closely spaced joints.

(c) The regional geological set-up of the area is important as detail structural deformation, stratigraphy and trend of litho types serve as guides to the suitability of the deposits. Younger formations are usually structurally less disturbed. Hinge of a fold or vicinity of a fault plane are generally more disturbed and hence least suitable for use as dimension stone.

(d) Thickness of a deposit is important and should be determined with due consideration of the effect of contact zone. The thickness of the deposit should be sufficient to ensure economic exploitation as well as recovery of sizeable blocks.

(e) The areas affected due to shearing and contact effects should be discarded as these effects render the deposit unsuitable.

(f) The intensity of weathering, when deep, necessitates elimination of the weathered portions, which in turn reduces the recovery.

(g) The grain sizes of the constituent minerals play an important role. The finer the grain, the better the durability. As such rocks with fine to medium size grains are preferred as dimension stones.

(h) Equi-granular texture is always preferred. Porphyritic and porphyroblastic textures have weak intergranular strength. Gneissic texture and flow textures are preferred where as schistose texture is not preferred because of presence of weak planes.

Marble

The term "Marble" is derived from the Latin work "Maarmor", which itself comes from Greek root, meaning a shining stone. Petrologically, marble is recrystallised (metamorphsed) limestone. Commercially, marble is any crystalline rock composed predominantly of calcite, dolomite or serpentine which can take polish. These constituent minerals have a hardness of 3-4 in Mohs' scale. A typical marble from Makrana (Rajasthan) analyses as follows :

$CaCO_3$	97.7
$MgCO_3$	1.2
Fe_2O_3	0.3
Insol. residue	0.9
Phosphoric acid	0.04

More than chemical composition, colour, pattern, physical strength, joint pattern and yield of large blocks determine the suitability of marble for use as dimension stones.

Sandstone

Sandstones have been used for centuries in construction of important monuments, palaces and forts in the form of blocks, rough slabs, ground slabs and in recent times as tiles. The cementing material of these sedimentary rocks determines the degree of compaction, colour and thus ultimately the quality of these stones as dimension stones. The Vindhyan formations constitute an excellent storehouse of this category of dimension stones because of their regular bedding, uniform grain size and durability. The Gondwana formations, especially the Athgarh sandstones have yielded dimensional stones of satisfactory durability which have been utilised in construction of temples around Bhubaneswar.

Limestone

Petrologically, the limestones, generally used as dimension stones, comprise dolomitic limestone which are usually hard, argillaceous and siliceous in nature. They are mostly used as flagstones or paving stones. Flaggy limestones as found in sizeable quantity in the states of Rajasthan, Andhra Pradesh and Karnataka displaying varieties of colours are popularly known as 'Kotah' stones of Rajasthan and 'Shahabad' stones of Karnataka. The state of Orissa, though a potential storehouse of limestone has yet no record of utilisation of this material as dimension stone.

Slate

The metamorphism of shales under pressure produce slates which are characterised by presence of close-set planes or cleavage along which they can be easily split into sheets. The commercially exploited slate deposits are in the states of Rajasthan, Haryana, Gujarat, Himachal Pradesh and Andhra Pradesh. The black and dark grey slates from Andhra Pradesh are popularly marketed as 'Cudappah' stones.

Laterite

Laterite, a typical derivative of alteration under tropical climatic conditions, is a porous, pitted and clay like rock with a hard limonitic protective crust containing a large quantity of iron in form of red and yellow ochre. In Orissa, these are used for building purpose as substitute of bricks in the districts of Cuttack, Nayagarh, Khurda, Puri and Ganjam.

Khondalite

Khondalites are a typical constituent of the Eastern Ghats and are petrologically quartzo-feldspathic garnetiferous sillimanite schist/gneiss.

These have been extensively used for construction of temples and are presently being used in the form of tiles for exterior decoration and also for ornamental and sculptural purposes.

3. EXPLORATION, OCCURRENCES AND RESOURCES

Rocks used as dimension stones occur in several geological formations in almost all the states of the Indian sub-continent.

In Orissa, the Archaeans which constitute about two-third of the landmass of the State host a variety of granite and rocks categorised as granite. In particular, the following geological terrains are important;

Chhotnagpur-Singhbhum - Bonai	Granite and gneisses of many types, dolerite, anorthosite, gabbro.
Eastern Ghats	Charnockite, khondalite, leptynite, anorthosite, pyroxene granulite, nepheline syenite.

The Purana formations host considerable quantities of slate, limestone and marble. The marbles and slaty phyllites constitute part of the Chhatisgarh-Indravati group of the Upper Proterozoic.

A systematic programme of exploration and assessment of dimension stone prospects has to follow the following sequential steps;

(i) identification of potential areas by studying regional geological maps, aerial photographs and landsat imageries,

(ii) detailed study of structural features (joints, veins, hairline cracks, intrusions, shearing effect etc),

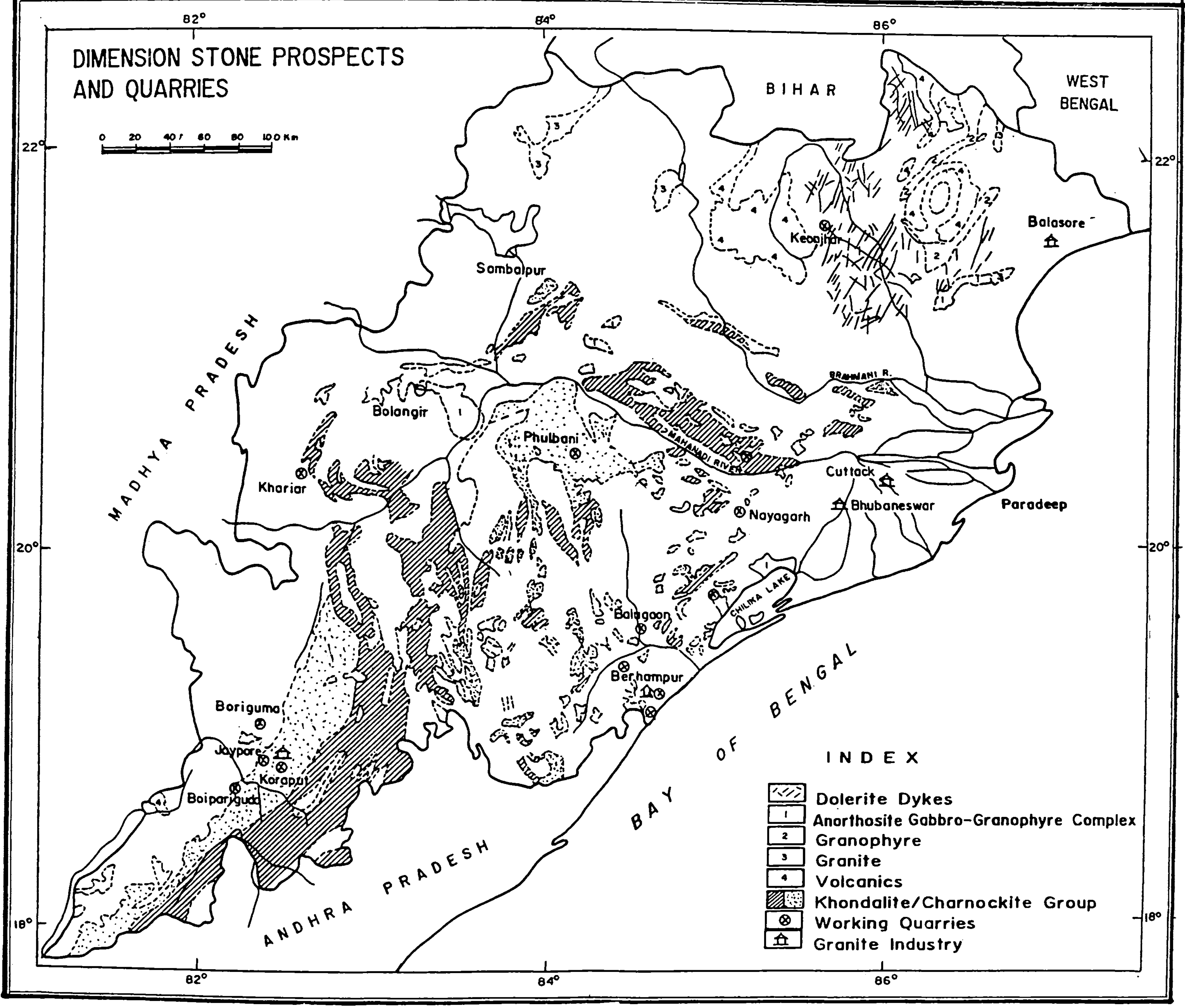
(iii) study of extent of weathering,

(iv) petrological and mineralogical studies including possible contamination effects,

(v) determination of physical and engineering properties,

(vi) study of colour consistency, grain size and texture,

(vii) assessment of the shape and size of the in situ rock/boulders and reserve,



DIMENSION STONE PROSPECTS AND QUARRIES

(viii) test quarrying, cutting and polishing,

(ix) extractable block-size and quarriability,

(x) study of logistics of the deposits.

Following preliminary investigation carried out by the State Directorate of Mining & Geology, about 100 potential occurrences of granite have been delineated and resources of the order of 9.36 million M^3 have been estimated upto a depth of 6 meters in an area measuring approximately 4,800 sq.kms.

Some selected occurrences of rocks which have been delineated for the purpose of quarrying dimension stone blocks are described in the following statement.

District	**Rock types**
Ganjam and Gajapati	Granite gneiss, pyroxene granulite, leptynite, augen gneiss.
Koraput, Malkangiri, Nawrangpur and Rayagada	Granite gneiss, dolerite, charnockite, pyroxene granulite, nepheline syenite.
Kalahandi	Granite gneiss, anorthosite.
Phulbani & Boudh	Granite, porphyries and gneisses.
Bolangir	Granite gneiss, augen gneiss, anorthosite.
Sambalpur	Granite, dolerite, basic granulite, nepheline syenite.
Dhenkanal & Angul	Granite, dolerite & basic rocks.
Keonjhar	Granite, granite gneiss, dolerite, pyroxene granulite, gabbro.
Cuttack	Charnockite.
Balasore	Gabbroic rocks.
Puri, Nayagarh & Khurda	Granite gneiss, anorthosite, charnockite.

The map enclosed shows the important dimension stone occurrences in Orissa, which are under exploitation

4. QUARRYING AND PROCESSING

Quarrying for dimension stones in Orissa is now confined to granite, khondalite, sandstone and laterite. Production of dimension stone blocks commenced in 1990 in the State. As on 1.4.1994, 345 quarry leases for granite have been granted covering an area of 2892 hectares. Production of dimension stone blocks during 1993-94 in Orissa was 3,436 cu.m valued at Rs. 12.7 million. Revenue in the shape of royalty earned by the State was to the tune of Rs. 3.2 million.

In India, major granite mining and processing activities are in the states of Karnataka, Tamil Nadu and Andhra Pradesh. Quarrying of granite blocks is carried out by simple manual semi-mechanised and mechanised methods. The basic techniques include drilling, blasting and wedge splitting. Drilling is done by means of jack hammers. In boundary zones, extraction is carried out by the use of feather and wedges in conjunction with short jack hammers holes. To prevent the possibility of development of cracks, blasting is done by using gun powder or detonating fuse. Loading and handling of blocks are done by mobile cranes and front end loaders.

Fully mechanised quarrying operations include flame torching (flame cutting), diamond wire sawing, linear drilling with or without blasting, hydraulic splitting, water jet cutting among others.

The processing of dimension stone blocks ranging in size from 0.5 m^3 to over 5 m^3 involves block dressing at the quarry site, cutting and sawing, grinding and polishing and edge cutting. The slabs, blocks and tiles are finished according to the specifications of the consumers.

The processing units set up in the State so far include those of

Grapco Granites near Balasore
Bhalotia near Jeypore
Konark Granite in Mancheswar Industrial Estate
Hari Granites in Jagatpur Industrial Estate.
Orient Black Gold (P) Ltd. at Berhampur
Sri Vishnu Granophyres near Jeypore
Bansal Granites (P) Ltd. near Balasore

5. PRODUCTION AND TRADE

The total production of dimension stone blocks in the country during 1990-91 was 23191 cubic metres consisting of granite, marble and slate. Export amounted to 822204 tonnes during 1992-93 and the foreign exchange earnings were estimated at Rs. 36,73,343/-. India's share in the international export is of the order of only 7%. Besides Italy which is the leading granite trading country, other countries which should be cultivated by producers in Orissa are Japan, Taiwan, Singapore, Australia, where demand is on the upswing.

6. OUTLOOK

Geological setting and results of preliminary investigations carried out indicate large resource potential of dimension stones in Orissa. It is necessary to pool the resources available with the Directorate of Mining and Geology, Orissa Mining Corporation and private entrepreneurs for evaluation, testing and development of the prospects.

There is a very large domestic market which may be targeted for marketing of dimension stones either in rough blocks or cut and polished form.

The economics of dimension stone quarrying depends to some extent on the recovery of usable blocks and disposal of large quantum of rejects. This aspect need special attention.

The State Government can play a major role in development of the dimension stone industry by providing good access roads, power supply and adopting a development oriented policy which can stimulate investment.

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Fireclay

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1. INTRODUCTION

The term Fireclay has been commonly applied to refractory clays associated with sedimentary formations which can withstand temperature of 1500°C or higher, Fireclay is basically kaolinite. On the basis of plasticity, fireclays are classified as plastic, semi-plastic and non-plastic. An important parameter of fireclays is refractoriness expressed in terms of Pyrometric Cone Equivalent (PCE), which should be minimum 18. Fireclay is almost exclusively used for manufacture of acid refractories of various grades and types.

2. GEOLOGY

Fireclay seams in India are confined to the Karharbari and Barakar Formations in Lower Gondwana and Athgarh Formation of Upper Gondwana. Occurrences of fireclay are also seen in Kamthi, Jabalpur and Maharajpur (of Rajmahal hills) formations. In Orissa, workable seams occur in both Talcher and Ib River coalfields in the districts of Dhenkanal, Angul, Jharsuguda and Sundargarh, in the Upper Gondwana Athgarh Formation in Banki subdivision of Cuttack district. Certain general observations may be made in regard to formation of fireclays. These are :

(1). The climate, ecological and pedological vis a vis sedimentological conditions favourable for the formation of fireclays evolved in two distinct periods during Gondwana sedimentation.

(2). Fireclay represents a temporary phase of quiescence in between upper flow regions.

(3). Fireclay seams unlike the coal seams, are of limited strike continuity and are at places disposed in lensoid manner. They have also limited dip-wise continuity.

(4). Fireclay seams are well developed either in the floor or in the roof or interbanded with thick coal horizons.

(5). Fireclay contains impressions of plants testifying their association with fossil forests.

(6). Fireclay has two modes of occurrence, (a) fairly well defined beds associated with coal seams and (b) lenticular beds associated with coarser clastic sediments.

(7). The formation of fireclay associated with coal seams is attributed to autochthonous weathering of clay minerals in the coal swamps leading to their progressive transformation into kaolinite, disappearance of felspar and eventually of quartz produced under the influence of lessivage by water charged with humic acids originating from the coal swamps. In fact, the sub-tropical climate prevailing, was responsible for hydrolysis of clay minerals leading to neoformation of kaolinite. At the end of the Damuda period, the forests no longer proliferated and the fireclay forming environment totally disappeared. However, during Jabalpur and Athgarh sedimentation, there was renewed tectonism in response to the rifting and drifting of the Indian plate and new depocentres evolved and depositional conditions simulated those of the thin fireclay lenses associated with the coarse Karharbari and Barakar sediments. The renewed tectonism and derivation of clastics from granitic uplands favoured the formation of lenticular fireclay beds in these sediments.

(8). The origin of the fireclays, not associated with any coal seams, is still an enigma. It is likely that the parent material of clay changed into refractory clay by progressive enrichment in kaolinite through diagenetic processes.

3. OCCURRENCES

As mentioned earlier, occurrences of fireclay are confined to three geographical belts, viz.,

a. Talcher Coalfield in the districts of Dhenkanal & Angul.
b. Ib River Coalfield in the districts of Jharsuguda and Sundargarh, and
c. Upper Gondwana Athgarh Formation in Banki sub-division of Cuttack district.

In Talcher Coalfield, fireclay has been encountered in the following collieries and locations :

Horizon	From (m) depth	Thickness (m)
Jagannath Colliery	Above Seam II	5-6
South Balanda Colliery	Above Seam I	3-4
Near Village Kaniha	10 - 40	2-3
Near Ghantikhal village	Basal Barakar, Surface	0.80

In Ib River Coalfield, occurrences of fireclay have been recorded near Jurabaga, Darlipali, Rampur, Kuropali, Baria pahar, Lukopoli, Khinda, Talabira, Rail, Bundia, Katabaga, Ainlapali, Chuliabarund, Kirarwa, Balpur, Kiripsera, Siarmal, Kulda among others.

The fireclay horizon is confined to the roof of the Rampur seam in the incrop region and does not occur at depth.

The quality parameters are

	Non-plastic	Plastic	High alumina
SiO_2 %	53-62	44-64	49-52
Al_2O_3 %	23.6-32	24-29	33-36
Fe_2O_3 %	2.4-3.2	1.8-3.3	1-1.20
PCE (Orton)	34	29-30	

In Belpahar area, fireclay occurs in Barakars dipping at 3° to 6° westwards. Soil and laterite form the surface capping. The rock types encountered within a depth of 20m are sandstone, fireclay, carbonaceous shale with stringers of coal. Fireclay seam in single or two sections is upto 5m in thickness. Clays of Talabasta area belong to the Athgarh Formation of Upper Gondwana. The rock types met with are laterite, sandstone (felspathic and ferruginous), sandy clay, ironstone shale and clay. Fireclay occurs interstratified with sandstone. Ironstone shale appears to be a marker horizon above fireclay bed. The fireclay of this are is non-plastic, hard, white to greyish white in colour and occurs in as many as 5 recognisable horizons, the thickness ranging from 0.5 to 3 m. The overburden to clay ratio ranges from 4:1 to 15:1.

A few typical analysis of non-plastic clay gave 29 - 35% Al_2O_3, 46-49% SiO_2, 0.8-1.5% Fe_2O_3, 0.8-1.8 TiO_2, 8-14 % LOI, PCE (Orton) : 31 - 33.

4. EXPLORATION AND RESERVE

The Directorate of Mining & Geology had carried out investigation in parts of Talcher and Ib River Coalfields and in Talbasta area by means of pitting and drilling. TISCO also had undertaken detailed proving in Talbasta and Belpahar areas by trial excavations, drilling; groove, core and bulk sampling. Considering the irregular nature of high alumina non-plastic clay in Talbasta area, drilling was carried at close grid of 40m x 40m.

The recoverable reserves of fireclay in the country as on 1.4.90 are estimated at 696 million tonnes. The State's reserves are placed at 108 million tonnes. However, high alumina non-plastic fireclay suitable for refractories for use in iron and steel industry would constitute about 5% of the total reserves. Besides, sizeable portion of non-plastic fireclay resources in Talbasta area has been included within the Chandka Elephant Sanctuary and therefore not available for extraction.

5. MINING AND PRODUCTION

There were 55 mining leases for fireclay in the State as on 1.4.94. Of these, 28 were in operation. District-wise break-up of leases and average annual production are given in the following statement :

District	No. of leases	Nos. in operation	Average annual production (in '000 tonnes)
Angul	2	2	4
Cuttack	18	11	60
Jharsuguda	7	3	15
Khurda	8	4	6
Sambalpur	3	1	1
Sundargarh	17	7	23

The State produced 108,000 tonnes during 1993-94 constituting roughly 20% of country's production. The major producers are :

Tata Refractories Ltd.	Talbasta (Cuttack)	18,000 tonnes
Konark Minerals	-do-	17,000 "
J.K & K.P. Jhunjhunwala	-do-	9,000 "
B.B. Sahu	-do-	8,000 "
P.L. Sharma	Siarmal (Sundargarh)	6,000 "
J. Parmanik	Kulda (Sundargarh)	7,000 "

The other producers include IPITATA Refractories Ltd., Sm. P. Pradhan, Sri N.K. Agarwal and Sri C.M. Das. Production of fireclay overlying the coal seams in Belpahar area was being carried out by Orissa Mining Corporation on agency basis.

Mining is mostly by manual method with 1.5 m high benches. Blasting is not required. In Talbasta quarry of TRL, overburden is removed by excavator-dumper combination. The bench dimensions are 4m (height) x 9 m (width). Fireclay is extracted manually in 1.5 m high benches.

6. SPECIFICATIONS

The only application of fireclay is as refractories. The BIS has not laid down any specific standards. However, the Sub-Committee on Refractory Raw Materials constituted by the Directorate General of Technical Development (DGTD) has recommended the following specifications :

	Grade I	**Grade II**	**Grade III**	**Grade IV**
a) Non-plastic/ Semi-plastic clay				
Al_2O_3	35-40%	32-35%	30-32%	
Fe_2O_3	1% max.	1-1.5%	1.5-2%	
PCE (Orton)	33 (min)	32 (min)	30 (min)	
b. Plastic clay				
Al_2O_3	30-32%	28-30%	22-28%	18-20%
Fe_2O_3	1-1.5%	2-3%	1-2%	1.5-2%
PCE (Orton)	30 (min)	28 (min)	26 (min)	18-21

Subsequently, the Expert Group constituted by the erstwhile Ministry of Steel & Mines recommended the following end-use classification.

	% Al_2O_3	**% Fe_2O_3**	**PCE (Orton)**
Non-plastic/ semi plastic clay	30 (min)	2 (min)	30 (min)
Plastic clay	18 (min)	3 (mix)	18 (min)

GENERAL REMARKS

The basin analysis undertaken in some of the coalfields has indicated that in a regime of rapidly shifting channels the depocentres of the fireclays were somewhat restricted and shifting. Thus, future investigation programme for fireclay should take cognizance of this possibility.

The growth of the refractory industry is closely interlinked with the technological developments in the iron and steel, ferro alloys, and cement industries which consume about 85% of the refractories in India.

The four major refractory plants of the State, viz., those of Tata Refractories Limited at Belpahar, Orissa Cement Limited at Rajgangpur, Orissa Industries limited at Lathikata, IPI-Tata Refractories Limited at Dhenkanal have adequate capacity for production of fireclay-based refractories. With the phasing out of O.H furnaces and adoption of Basic Oxygen Process of steel making, demand for the conventional fireclay based brick type refractories is declining. However, demand for high alumina fireclay particularly of the non-plastic type will be sustained.

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Gemstones

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1. INTRODUCTION

The qualities that characterise gemstones are natural origin, beauty, durability, uniqueness, rarity, hardness and chemical resistance. Beauty is essentially a subjective concept, and is based on lustre, transparency, brilliance and colour. Of the 2,500 mineral species known, only about 100 possess all the attributes required in gems. Silicates constitute the greatest number, oxides the second largest group; sulfides, carbonates and sulphates make up a small group. Diamond because of high value is treated as an exclusive species in all discussions and descriptions of gemstones. The properties and characteristics of some of the common gemstones are given in Table-1.

The major diamond producing countries include Republic of South Africa. Botswana. Angola, Namibia, Zaire, Australia, Venezuela, Brazil, North eastern Siberia. Countries in which major gemstone deposits (other than diamond) occur are Afghanistan, Australia, Brazil, Myanmar Sri Lanka, Columbia, Kenya, Madagascar, Mexico, Tanzania, Zambia, and Thailand.

Indian occurrences of gemstones (other than diamond) have been recorded in most of the states, while occurrences of diamond are confined to Majhgawan, Hinota, Behradih, Payalikhand and Jhangra areas in M.P., Wajrakarur and Mehboobnagar areas of A.P. and gravel beds of Mahanadi river in Orissa.

Table - 1,
Properties and Characteristics of some common gemstones

Name	Composition	Colour	Moh's hardness	Specific gravity	Refractive Index (RI)	Recognising characters
Amethyst	Silica	Purple	7.0	2.65	1.56	RI, double refraction, transparent
BERYL						
Aquamarine	Beryllium aluminium silicate	Blue-green to light blue.	7.5-8.0	2.63-3.80	1.58	Double refraction, Refractive index
Emerald	-do-	Green	7.5	-do-	-do-	Dichroism, RI.
Heliodor	-do-	Yellow green	-do-	-do-	-do-	Distinctive colour
CORUNDUM						
Ruby	Aluminium oxide	Rose to deep purplish red	9.0	3.95-4.10	1.78	Inclusions, fluorescence
Sapphire	-do-	Blue (typical)	-do-	-do-	-do-	Inclusions, double refraction, pleochroisn
DIAMOND	Carbon	White, Blue-white, yellow, brown, green, pink, blue	10.0	3.5	2.42	High RI, dispersion, single refraction, hardness, cut, lustre
IOLITE	Aluminium magnesium silicate with iron.	Gray, light or dark blue, violet	7-7.5	2.53-2.65	2.54	Occurs as multifaceted prismatic crystals, often strongly pleochroic
CHRYSOBERYL						
Alexandrite	Beryllium aluminate	Green by day, red by artificial light	8.5	3.5-3.84	1.75	Dichroism, inclusions in synthetic sapphire
Cat's eye	-do-	Greenish to brownish	-do-	-do-	-do-	Sp. gravity and translucence
FELDSPAR						
Moonstone	Alkali aluminium silicate	White	6.0-6.5	2.77	1.52-1.54	Blue sheen, opalescent
GARNET	Complex silicate	Brown, black, yellow, green, ruby red, orange	6.5-7.5	3.15-4.30	1.79-1.98	Single refraction, anomalous strain
TOPAZ	-do-	White, blue, green.	8.0	3.4-3.6	1.62	Refractive index
TOURMALINE	-do-	All, including mixed.	7.0-7.5	2.98-3.20	1.63	Double refraction, Refractive index.
ZIRCON	Zirconium silicate	White, blue, brown, yellow, green	6.0-7.5	4.0-4.8	1.79-1.98	Double refraction, sp. gravity, strongly dichrocic, wear on facet edges.

2. GEMSTONES (other than Diamond)

The gemstones whose occurrences have been recorded in Orissa include emerald, ruby, sapphire, aquamarine, heliodor, chrysoberyl, cat's eye, alexandrite, tourmaline, zircon, topaz, moonstone, amethyst, smoky quartz, garnet (hessonite, rhodolite and almandine) among others. These are mostly localised within the Eastern Ghats Granulite belt while a few are associated with the Deogarh-Pallahara-Mahagiri group of rocks of the Iron ore Super Group.

The Quaternary sediments and particularly the gravel beds in Mahanadi river have yielded garnet, topaz, cat's eye and also diamond.

2.1 Desirable Qualities of Gemstones.

As mentioned earlier,, the three cardinal virtues of gemstones are their beauty, durability and rarity. The other desirable features of gemstones are;

i. Bright Colours,

ii. Optical properties such as chatoyancy, asterism, opalescence, pleochroism etc.,

iii. Hardness (should be more than 5 on the Moh's scale and uniform),

iv. Fractures and inclusions (should be free from these defects.),

v. Zoning (should be free from zoning),

vi. Brittleness (should not be too brittle),

vii. Clarity (should preferably be transparent and water clear), and

viii. Amenability to cutting and polishing

2.2 Depositional Environment

Gemstones occur as disseminations pockets, patches and narrow linear veins in the host rocks. They are often, reworked from their host rocks, get transported over long distances and get deposited in younger gravel beds. The following depositional environments of gemstone bearing host rocks will be of assistance in exploration :

a. Gemstones deposited by water on the earth surface,

i. Concentrated by surface waters (e.g. alluvial diamonds

b. Gemstones of igneous-hydrothermal origin.

- i. Formed directly from molten rock (e.g. sapphire, ruby)
- ii. Hydrothermal (e.g. amethyst, "Imperial" topaz).
- iii. Formed in pegmatites (e.g. aquamarine, tourmaline, topaz).

c. Gemstones formed by very high temperatures and pressures.

- i. Low pressure, regional metamorphism (e.g. emerald).
- ii. High temperature, regional metamorphism (e.g. jadeite)

d. Gemstones formed at great depth

- i. Mantle thrust sheet gem deposit e.g. peridot
- ii. Diamond pipes.

The exploration programme would obviously take into account the following aspects as well

1. (1) geological structure and morphology as interpreted from satellite imageries and aerial photographs;
2. (2) study of fluid and solid inclusions,
3. (3) well equipped gemmological/petrological laboratory and
4. (4) portable processing equipment to be used in the field.

In gemstones, qualitative and quantitative assessment of a prospect are done by exploratory mining - accompanied by processing involving scrubbing, jigging, washing and screening in the field by means of portable processing plants.

2.3 Occurrences

The gemstone occurrences of Orissa are localised in the following geological domains;

- a. Eastern Ghats Granulite belt
- b. High-grade supracrustal rocks
- c. Mafic and ultramafic complexes
- d. Alkali syenite
- e. Quaternary sediments and gravel beds.

Table 2 further illustrates this.

Table 2: Localisation of Gemstones and associated host rocks in Orissa.

Name of the Gemstone.	**Host rocks**
1. Ruby and sapphire,	a. Contact of pegmatite and ultramafic rocks. b. High grade pelitic (kyanite-sillimanite) schists c. Nepheline syenite d. Cordierite-sillimanite-garnet schists and para gneisses.
2. Emerald and Aquamarine	Contact of beryl bearing pegmatite with ultramafic rocks.
3. Alexandrite and Chrysoberyl cat's eye	Pegmatites in Khondalite suite of rocks
4. Rhodolite, almandine and uvarovite garnets; fibrolite cat's eye, iolite.	High grade pelitic schists
5. Amethyst, topaz, aquamarine, heliodor, tourmaline, moonstone, labradorite microcline.	Pegmatite.

The Eastern Ghats Granulite belt comprising mainly khondalite charnockite suite of rocks and their variants interbanded with mafic-ultramafic complexes, anorthosites and alkaline complexes and intruded by potassic granites, pegmatites and quartz veins host most of the gemstone occurrences of the state. The following is a belt-wise description of the gemstone occurrences in Orissa.

Table - 3

Serial No.	Name & Location of the Gemstone belt	Gemstones and associated rock types.
1.	Magarmuhan-Jhilli Nuagan (Angul dist)	Garnet (rhodolite) and corundum in ambhibolite and quartz-mica-kyanite schist association, with garnets having more affinity with mica rich zone and corundum with kyanite rich zone.
Sambalpur district (Sl. Nos 2-4)		
2.	Charbhati-Beldihi	Near Rairakhol, rock types are typical Eastern Ghats Super Group assemblage with pegmatites emplacing khondalite suite of rocks, yielding aquamarine. Occurrences of zircon in syenite association, tourmaline associated with pegmatites and heliodor have been reported.
3.	Bagdhapa-Tabloi	Aquamarine, garnets (rhodolite and almandine), iolite and amethyst in EG Super Group setting with pegmatites and quartz veins intruding. Occurrences of garnet at the contact of quartz-felspathic gneiss and amphibolite.
4.	Meghpal-Ranchipada (in Meghpal R.F)	EG Super Group assemblage with pegmatites intruding, occurrences of red opaque corundum. Pyrope garnet, iotite, green tourmaline and aquamarine recorded. Most important is the rare occurrence of alexandrite in biotite schist developed at the contact of granite pegmatite and peridotite.
5.	Budido-Palsama-Jharposi (Deogarh district).	Hessonite at the contact of garnetiferous gneiss and amphibolite and rhodolite at the contact of quartz-sillimanite schist and amphibolite recorded over a fairly long belt.
6.	Bagdihi (Jharsuguda district)	Green tourmaline in a zoned pegmatite body of about 50m length in an assemblage of porphyritic granite gneiss, amphibolite and schists.
Bolangir District		
7.	Ghuchepali-Antarla	An important gem belt of the EG granulite terrain which has yielded emerald, topaz, heliodor and aquamarine; occurrences associated with low dipping unzoned pegmatites emplacing granite grneiss.
8.	Ghumsar -Dehli	Chrysoberyl and Cat's eye associated with simple pegmatites (disintegrated and partly lateritised) emplacing gneissic country rock of the EG Super Group assemblage.

9.	Muribahal-Tentelkhunti	Orange, brown and yellow colour zircons in calc-granulites and chrysoberyl in zoned pegmatites intruding into gneissic country rocks, occurrences of aquamarine, topaz and amethyst have also been reported.
10.	Saraibahal-Suklimuri	Green beryl, aquamarine, heliodor and amethyst associated with zoned pegmatites intruding meta-ultramafites.
11.	Naktamunda-Siali	Known for excellent quality rhodolite garnets, which occur at the contact of pegmatites with garnetiferous granite gneiss and mica schist.

Subarnapur district

12.	Badmal-Mursundi	The belt extends from Birmaharajpur in the south upto Badmal in the north and beyond and covers an area of 350 sq.km. As many as 200 pegmatite bodies have been delineated, emplacing EG Super Group comprising garnetiferous granite gneiss, basic granulite and calc-granulite. The gemstones include greenish blue to sea blue aquamarine, the colluvial zone yielding most of it.
13.	Binika - Sonepur	A linear belt extending from Binika upto the confluence of Mahanadi-Tel rivers on the right bank of Mahanadi covering an area of about 50 sq. km. exposes garnetiferous granite gneiss and migmatites. Gemstones recovered are from gravel beds of Mahanadi river and include garnets, cat's eye, topaz, smoky quartz and diamond.

Boudh district

14.	Baudh-Ramgarh	Gem quality garnets, chrysoberyl, cat's eye, topaz, zircon, moonstone, agate and diamond are being recovered from the gravels of Mahanadi river. The gravel beds overlie augen gneiss.
15.	Kantamal - Manmunda.	Gravel beds with possible porphyritic granite gneiss affinity in Mahanadi river bed over an area of about 45 sq.km. in this belt have yielded garnets, topaz, cat's eye, iolite, tourmaline and diamond.

Kalahandi district

16.	Jillingdhar-Hinjlibahal	This belt extends for a length of 25 kms. The EG Super Group is represented by meta-pyroxenite, granite gneiss, amphibolite and calc granulite. Occurrences of corundum/ruby have been located at the contact of meta-pyroxenite and granite gneiss marked by the development of actionolite tremolite - vermiculite aggregates carrying irregularly ramified veins of quartz. Ruby occurs in the eluvial zone of altered meta-pyroxene below an alluvial overburden of 0.5 to 4 meters thickness. Jillingdhar ruby prospect is presently under exploitation. The ruby is mostly red to blood red in colour, of excellent clarity, and lustre

17.	Orhabahala-Urharanga	Iolite, deep blue in colour showing dichroism occurs in association with cordierite gneiss. Cordierite gneiss occurs as discontinuous lensoid bodies, pockets within migmatised khondalite.
18.	Ghatpara-Singjharan	Hessonite garnet and zircon have been recovered from alluvials of calc granulite and granite gneiss contact as well as from pegmatites within the calc granulites.
19.	Sirjapali-Tundla	Simple pegmatites cutting across granites containing xenoliths of pyroxene granulites have yielded chrysoberyl cat's eye.
20.	Banjipadar-Sargiguda	Occurrences of garnets (rhodolite and almandine) associated with meta-pelitic schists and garnet-pyribolite, blue opaque corundum, enstatite cat's eye, apatite and aquamarine have been recorded.

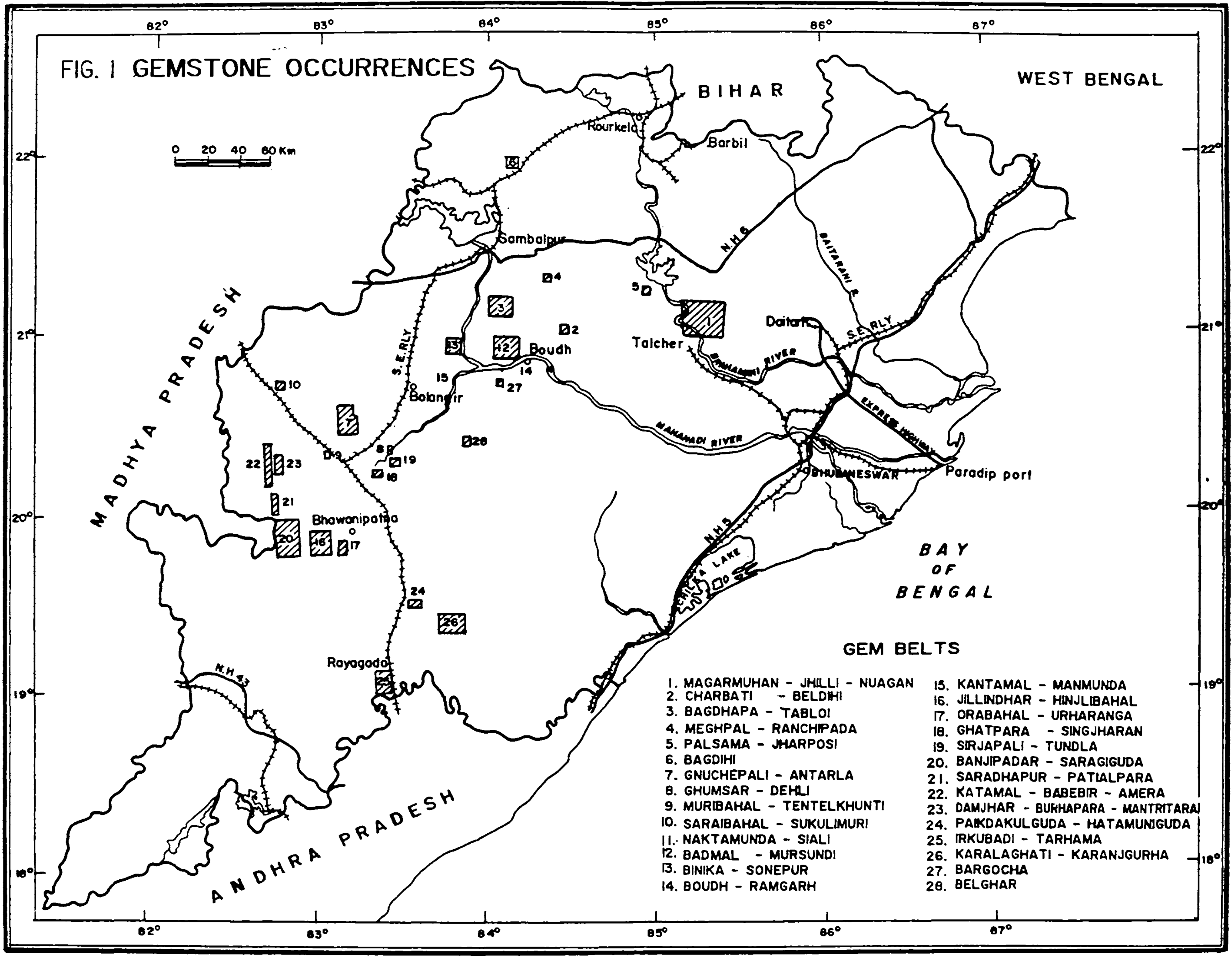
Nawapada district

21.	Sardhapur-Patialpada	Pink and red coloured garnets are associated with garnet pyribolite, which occur as enclaves within gneisses and traversed by quartz-felspathic permeation. Minor occurrences of blue iolite and fibrolite have been recorded.
22.	Katamal-Babebir-Amera	The EG Super Group is represented by charnockite, khondalite and its variants, amphibolite, meta-pyroxenite and intrusives like granite, alkali syenite, syenite-gabbro, pegmatites and quartz veins, Gem mineralisation is that of transparent to light blue sapphire, which occur in association with syenite pegmatite and mostly confined to colluvial zone. Studies involving silica deficient syenite pegmatite indicate growth of sapphire by fractional crystallisation from a volatile rich alkaline melt in a slow cooling process.
23.	Damjhar-Burhapara-Mantritarai.	This belt located close to Katamal-Amera is characterised by occurrences of almandine garnets mostly within the colluvials and also in association with biotite schist developed at the contact of quartz-felspathic gneiss and amphibolite. Occurrence of iolite has also been recorded.

Rayagada district

24.	Paikdakulguda Hatamuniguda.	Occurrence of chrysoberyl/cat's eye is observed in pegmatite emplacing khondalite. Chrysoberyl has also been found in the colluvial zone.
25.	Irkubadi-Tarhama	Occurrence of sillimanite cat's eye has been recorded in weathered colluvial zone at the contact of khondalite and quartz felspathic gneiss and occasionally located in the weathered khondalite.

FIG. 1 GEMSTONE OCCURRENCES



26.	Karlaghati-Karanjgurha	Occurrence of chrysoberyl has been observed in association with pegmatites.
Phulbani district		
27.	Bargochha (South of Manmunda).	Tourmaline in pegmatites
28.	Belghar.	Chrysoberyl cat's eye associated with pegmatites.

Fig. 1 shows the Gemstone occurrences in Orissa.

3. DIAMOND

Ancient civilisations were fascinated by the exceptional hardness of diamond, although coloured gems were more aesthetically pleasing. It was only after the development of modern type of brilliant cut at the beginning of the twentieth century that showed it in all its glory and diamond has reigned supreme as the most important and valuable gemstone ever.

India was the only producer of diamonds till the first quarter of the 18th century when Brazil entered the field followed by South Africa during the 19th century. The Great Moghul (787.5 carats), Kohinoor (106.5 carats), Hope (86 carats), Pitt or Regent (413 carats), Nizam (277 carats), Orloff (194 3/4 carats), Daria--Noor (186 carats) and Duke (133 1/5 carats) are of Indian Origin. India now produces only 19,500 carats, almost entirely (93%) from Majhgawan mine of NMDC in Panna field of M.P. as against world production of about 105 million carats. India is the world's largest producer and exporter of cut and polished diamonds. India imported rough diamonds valued at Rs. 80,640 million and exported cut and polished diamonds worth Rs. 113,710 million during 1993-94.

3.1 Geological Set-up, Exploration and Potential target areas

Diamond occurrences are associated with three types of geological settings, viz, kimberlite / lamproite pipes, conglomerate beds and alluvial gravels. As about 80% of world's natural diamond production are derived from primary sources, our efforts should be directed to delineate diamondiferous kimberlite/lamproite clusters and the methodology to be adopted include;

a. Scanning of potential areas by low flying, close grid high resolution aeromagnetic survey.

b. Study of available satellite imageries and aerial photographs.

c. Ground geophysical survey,

d. Meticulous stream sediment sampling for indicator minerals, (pyrope garnet, magnesium ilmenite, chrome spinel etc.)

e. Proton-probe analysis,

f. Determination of size distribution of micro-diamonds.

g. Drilling and bulk sampling (depending on the results of e & f.)

The target areas are the ancient cratonised areas characterised by low heat flow and deeper crustal thickness (low gravity values) with signs of reactivated deep seated lineaments/rifts.

As regards age, origin and emplacement, most diamonds were formed more than 990 million years ago at depths of 150-200 km below the surface from either of the two rock types, peridotite and eclogite. They were stored under cratons at least 110 km. below the surface for varying periods of time, some as long as 3,200 million years before being transported to the surface. Kimberlite and lamproite, the two rock types in which primary diamonds are found, are generally much younger and are not the rocks in which diamonds crystallize. They are merely the transporting media that bring diamonds to the surface by mechanism that is not completely understood. Carbon isotope studies indicate that carbon from which peridotitic diamonds crystallize originates from a homogeneous source within the earth's mantle, whereas carbon for eclogitic diamonds probably originates from sources on the earth's crust that have been subducted below cratons by plate movements.

While discussing diamonds, it would be pertinent to define what constitute **kimberlite** and **lamproite** and what are **eclogite** and **peridotite.**

Kimberlite is a dark coloured hybrid, volatile-rich, potassic, ultramafic igneous rock derived from deep in the earth which occurs near the surface as small volcanic pipes, dykes and sills. It is composed principally of olivine, (both as phenocrysts and in groundmass) with lesser amounts of phlogopite, diopside, serpentine, calcite, garnet, ilmenite, spinel and or other minerals, diamond is only a rare constituent. Model of a kimberlite diatreme is shown in Fig.2.

Lamproite refers to a group of hybrid igneous rocks with a characteristic gray to greenish gray mottled appearance, ultrapotassic and magnesium rich. The primary magmatic crystallisation products, most notably olivine,

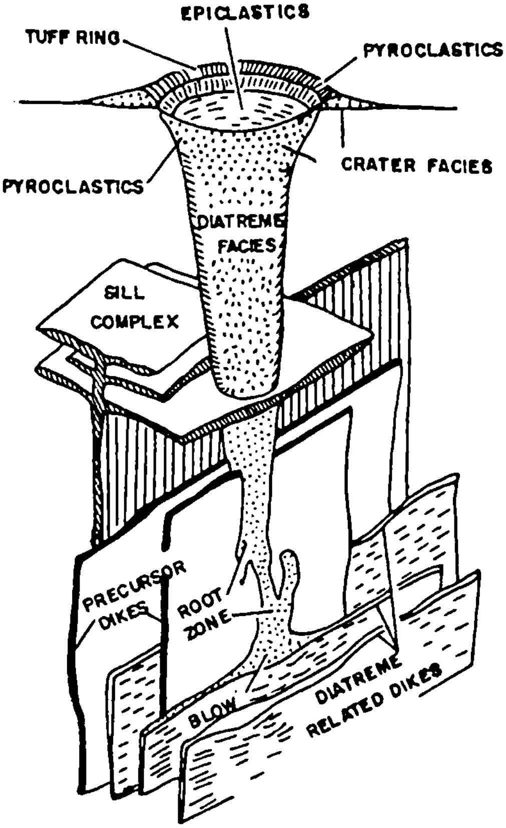


FIG.2 MODEL OF A KIMBERLITE DIATREME

AFTER: MITCHELL, 1986

occur both as phenocrysts and as groundmass constituents. Lamproites like kimberlites, occur as pipes, dykes and sills, but lamproite pipes resemble champagne glasses, rather than cones, in shape.

A comparison of the minerals present in the two rock types is particularly informative (Table - 4).

Table - 4

Minerals	**Kimberlite**	**Lamproite**
Minerals that crystallize directly from kimberlite and lamproite magmas.		
Major		
Olivine	✓	✓
Diopside	✓	✓
Phlogopite	✓	✓
Calcite	✓	
Serpentine	✓	
Monticellite	✓	
Leucite		✓
Amphibole		✓
Enstatite		✓
Sanidine		✓
Minor		
Apatite	✓	✓
Perovskite	✓	✓
Ilmenite	✓	✓
Spinel	✓	✓
Priderite		✓
Nepheline		✓
Wadeite		✓
Xenocryst minerals derived from the upper mantle		
Olivine	✓	✓
Garnet	✓	✓
Clinopyroxene	✓	✓
Orthopyroxene	✓	✓
Chromite	✓	✓

Eclogite is a coarse-grained ultramafic rock consisting essentially of a granular aggregate of red garnet (almandine-pyrope) and green pyroxene (technically jadeitic clinopyroxene or a solid solution between jadeite and diopside), with minor amounts of rutile, kyanite, corundum and coesite. Eclogite is indicative of a high pressure -temperature, environment (specifically high pressure) consistent with that in which diamonds form.

Peridotite is a coarse-grained ultramafic rock consisting chiefly of olivine with or without other mafic (high in Fe and Mg) minerals such as pyroxene. Garnet and spinel frequently occur in small amounts. Peridotite is believed to be the most common and abundant rock type in the earth's mantle. Most peridotitic diamonds are formed in garnet bearing harzburgite with minor amounts formed in lherzolite.

Not all kimberlite (KL) pipes are diamond bearing. The best known lamproite pipe is that of Argyle of Australia. Most of the productive pipes however are of kimberlite origin. Of the total number of kimberlites world wide (could be around 3,500 or more) only 50-60 have ever been economic. Most of the well-known diamond producing pipes have a surface area of between 5 and 30 hectares; in South Affrica, they typically contain about 1 carat of rough diamond per 5 tonnes of kimberlite material.

The known KL pipes in India are :

i. Majhgawan (Lamproite 2), Hinota in Panna district of M.P.

ii. Behradih, Payalikhand, Jhangra and Kodomalle areas in Raipur district cratonic and platform covered cratons of M.P. close to Orissa border and within Orissa (Eastern Ghat Mobile zone) and

iii. Wajrakarur, Lattavaram and Chigicherla in Anantapur district; Maddur Kotakonda area in Mehboobnagar district of Andhra Pradesh.

3.2 Prospects in Orissa

Record of alluvial diamond recovery dates back to before the 18th century and the locations are junction of Ib and Mahanadi rivers and Hirakud (now submerged). Recent interest for search of diamond revived following recovery of a few pieces of diamond from Mahanadi river bed upstream of Baudh by officers of the Directorate of Mining & Geology, during the 1980s and later by the Orissa Mining Corporation. The recent discovery of diamondiferous KL pipes in Raipur district of M.P. with similar geological setting across the border in Orissa and presence of indicator minerals enhance the prospect of locating diamondiferous pipes in western Orissa. An UNDP Project is under implementation in the state since 1991 for exploration and development of gemstone potential and diamond has been included in the programme since later part of 1992. The exploration project will have valuable inputs in the form of magnetic anomalies from the Australian - aided high resolution aeromagnetic survey which covers the potential Archaean and Proterozoic terrain. On a broader frame, the following areas have been identified for diamond exploration.

1. Proterozoic sediments overlying Archaean basement in Nawapara district covering an area of 1,900 sq.km.
2. Parts of Singhbhum-Orissa craton, which stabilised around C. 3000ma.
3. Mahanadi graben zone north of and parallel to Mahanadi river course, may mark of reactivation of neighbouring fractures in Archaean terrain.
4. Palaeo alluvial diamond prospect in Mahanadi river bed and Morjakud island in Boudh district.
5. Remnants of Hirakud island downstream of Hirakud dam.

4. MINING AND PROCESSING

4.1 Mining

Gemstone mining in the state is presently confined to the ruby prospect of Jilingdhar in Kalahandi district and the lessee is Gem corporation of Orissa, a joint sector venture with the Orissa Mining Corporation. The lease area comprises 35 hectares. The opencast mining operation is designed to recover the gemstone from the eluvial zone in the first phase. The operations consist of stripping of overburden materials and processing of the ruby bearing materials by a mobile alluvial processing plant for recovery of gem quality ruby. Gemstone mining elsewhere is no different. It ranges from manual pick and shovel mining - washing panning to mechanised operations involving deployment of blast hole drill, excavators, dozers and dumpers. But use of process equipment is common, which includes scrubbers and disintegrators, washers and pulpers, screens, jigs, sorting conveyors and tables.

The mechanised opencast mining operations in Majhgawan diamondiferous pipe of NMDC comprise development of 7.5m high benches through the use of IR rotary drill, poclains, wheel loader, dragline, dumpers for extraction of annually 1,50,000 tonnes of kimberlite tuff. Processing operations include crushing, grinding, screening, jigging and hand picking of diamonds. A Heavy Media Separation (HMS) plant, X-ray sorting and optical grading have been introduced to optimise recovery.

4.2 Processing of rough gemstones

Processing of gemstones is different for different grades of rough gems. An outline of grading and processing systems adopted is given here

Grading

Based on the colour, transparency, optical properties and clarity, the rough gemstones are classified into the following grades;

- Facet
- Star
- Cabochon
- Tumbling
- Carving

Processing

The processing unit is called a "Lapidary unit". After grading, the rough gemstones are processed as follows;

Cutting and polishing (Faceting and Carbochon styles).	Facet grade -->Faceted gems Star and cabochon grades --> Cabochon gems.
Tumbling grade	Tumbling and polishing --> Beads and necklaces
Carving	done by hand.

All faceted gems are usually shaped into round, oval, square, rectangle, pear, heart and marquise shapes, Cabochons are usually made either into round or oval shapes.

All gems are made in internationally accepted sizes, measured in millimeters and known as "calibrated stones", Only calibrated stones are in demand in manufacture of jewellery.

5. SYNTHETIC AND ARTIFICIAL STONES

The very high cost of precious stones has encouraged attempts to produce synthetic stones including diamond. Rough synthetic stones made of pure alumina and cubic zirconia (CZ or American diamond), in a wide range of colours are manufactured in India. The techniques used for synthesizing include flame fusion, flux, hydrothermal and pulling growth. Many of the gemstones are treated or enhanced to improve their quality and appearance by processes such as bleaching, staining, dyeing, colour coating, surface impregnation, lasering, heat treatment and irradiation, artificial inclusions, gel filling of cracks among others. Another important development is the crystal growth technology. One of the criteria for distinguishing a natural stone from synthetic/artificial one is the nature of inclusions.

6. INDUSTRY, TRADE AND MARKETING

The world trade for diamonds is almost entirely controlled by De Beers Consolidated Mines Ltd. and its subsidiary. Production, processing and marketing of diamonds are well organised. In contrast, the activities in coloured stones are largely unorganised and scattered, illicit mining rampant and it is difficult to estimate the quantity and value of rough gemstones mined and consumed in the country.

Gemstone industry in India is totally dependent on import of rough stones, diamonds accounting for about Rs. 80,640 million and coloured stones around Rs. 1,500 million during 1993-94. Exports total led Rs. 116,800 million and the net foreign exchange earning amounted to Rs. 34,660 million, a very significant share in the country's export earnings.

The principal diamond cutting centres are Surat, Navsari, Ahmedabad, Bhavnagar, Valsad etc. in Gujarat and the suburbs of Bombay. Some units also exist in Trichur, Goa, Jodhpur and Calcutta. In coloured stones, the principal cutting centre is Jaipur, Processing is also being done in Cambay. In Orissa, 9 lapidary units have been set up.

7. CONCLUDING REMARKS

Prospect of locating diamondiferous KL pipes, alluvial diamond and coloured stones in Orissa backed up by the UNDP project and the Australian-aided high resolution aeromagnetic and radiometric survey and on consideration of detection of indicator minerals and favorable geological set up in the broadly identified belts is rated high. The programme needs to be funded adequately and supported by well equipped laboratory facilities for detection of indicator minerals and gem testing.

Certain legislative changes are called for to permit coverage of large areas for exploration of diamonds.

The state could develop modern lapidary units with the latest calibration facilities to process the roughs for use in the domestic market and for export.

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Gold

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1. INTRODUCTION

Incidences of both primary and secondary gold are known far and wide in the various tracts of India including Orissa. Winning of this elusive yellow metal by ancients dates back to at least 2000 years before the Christian era. Such activities, perhaps, continued till about 1000 AD (Ziauddin and Naryanaswami, 1974). The remains and the reminiscences of those ancient gold mining centres in the form of tunnels, pits, adits, shafts, rock dumps / debris, grinding implements and surface gold shows in streams attracted the attention of early European gold prospectors in late nineteenth century. Thus, modern gold mining was ushered in India in 1880 AD in Wynad Gold Field of South India. Since then gold mining activity has been continued uninterrupted mostly in South Indian shield and sporadically in Eastern Indian shield. The overall gold production in the country reached great heights in the early part of this century i.e. 15 to 20t between 1900 and 1920. Thereafter, production gradually dwindled to 5.6t in 1948 and to 1.9t in 1988. Currently, gold is won from four operating mines, all located in South Indian shield, and as by-product from several base metal mines. However, the total production is just under 2 t, which is meagre enough in comparison to the current world mine gold production of 2,281 t (1993). India's domestic consumption of gold is well over 200 t per annum and has been showing an increasing trend even in very recent time.

Exploration and development of gold deposits have remained a dominant theme throughout the world during the last one and half decades or so and this has resulted in over 100% increase in mine gold production. Maximum successes in exploration have been achieved in the major Archaean cratonic blocks of Australia, Canada, Brazil, Africa and in Cenozoic Pacific Ocean rim. In contrast, the progress of gold exploration and especially development in India have remained sluggish although several potential geological environments have been identified.

In Eastern Indian shield, supracrustal provinces such as the Iron Ore Group (IOG) of Archaean age, the adjoining Proterozoic fold belts and the platformal basins have been targeted for gold exploration. In Orissa, the IOG rocks and related volcano-sedimentary units occurring in the cratonic block of Singhbhum, Bonai and Bastar (south western

Orissa) and also their contact zones with the high grade mobile belt (Eastern Ghats) constitute highly potential geological environment for economic grade gold search. Apart from this, there are other less known auriferous blocks in Proterozoic successions which are awaiting evaluation. This paper outlines the current status of knowledge and future outlook of gold exploration in Orissa.

2. GOLD DEPOSITS OF THE WORLD- AN OUTLINE

Gold deposits are quite widespread in space and time and their primary (mine) production is contributed by hundreds of deposits all over the world. The geological history of the earth has been marked by a number of epochs of gold mineralisation and several metallogenic provinces have been identified. Over 55% of the world's cumulative gold production has come from rocks that are more than 2,500 m.y. old. Gold deposits are rare in Early Proterozoic, nearly absent in Mid Proterozoic sequences and reappear in late Proterozoic and Phanerozoic eugeosynclinal volcano-sedimentary successions of Palaeozoic, Mesozoic and particularly Tertiary periods (Hutchinson, 1987).

The palaeoplacer deposits (quartz-pebble - conglomerate type) is responsible for bulk (40%) of the world gold production. The major part of this production has come from unique Witwatersrand basin of South Africa which occur at the base of Proterozoic sequences (2800-2600 m.y.). Similar palaeoplacers of younger age (2400 - 2200 m.y.) are found elsewhere in the world where gold mineralisation is much less significant compared to the ones in Rand basin. Next to this are the lode deposits of Archaean, Proterozoic, Palaeozoic and Mesozoic ages occurring in various volcano-sedimentary successions; the cumulative contribution of all being 18%. The Archaean lode gold deposits have remained the chief contributor in this category and recent exploration has been showing still vast potential of this ubiquitous type. BIF hosted deposits enclosed in graywacke or turbidites of Archaean and Late Proterozoic age have contributed about 5% of total gold. In short, over 60% of the total gold produced so far in the world has come from Precambrian deposits. Tertiary is the next major metallogenetic epoch for gold, the cumulative total production is of the order of 13 to 14%. In recent years major discoveries from the circumpacific countries from this type of deposits are contributing sizably to the world gold production. This mobile belt holds great promise for future discoveries also. The deposit types include epithermal deposits and volcanogenic massive polymetallic sulphide deposits. Large quantity of gold (nearly 20%) has been won, particularly in yester years, from various placer deposits of Tertiary to Recent ages. Of late, the secondary residual type lateritic gold deposits of Australia and Brazil have been gaining importance and this type is expected to contribute significantly to the world gold production in near future. A geological classification of the world gold deposits is shown in Table-I.

Table - I

World Gold Deposit Types

Sl. No.	Type of deposits	Host Rock	Structural Style and Tectonic setting	Gold Grade	Age
1.	Palaeoplacer	Quartz-pebble conglomerate, Quartzite.	Cratonic foreland basin, platform, fault-bounded basin margin, stratabound in successive conglomeratic layers.	8 g/t	Late Archaean to Early Proterozoic
2.	Lode deposits in greenstone belt	Fe-rich tholeiite basalt, Mg-rich mafic-ultramafic flows, dolerite, acid flows, pyroclasts, conglomerate, turbidite, carbonaceous sulphide schist.	Veins in ductile to ductile-brittle shear zones, discordant veins, stockworks, disseminations.	2.5 to 16 g/t	Mid to Late Archaean, Early Proterozoic, Palaeozoic, Mesozoic
3.	Iron formation deposits	BIF of all facies	Stratiform, also in structurally favourable sites, mineralised pipes, pods, saddles and disseminations.	0.31 to 15 g/t	Late Archaean.
4.	Lode deposits of Tertiary Volcanics	Calc-alkaline volcanic suite, Intermediate to felsic volcanics and shallow plutons.	Epithermal veins, subduction process related, tensional openings, breccias	Low to very high (upto 70 g/t)	Tertiary to Recent
5.	Copper porphyry deposits	Granite to monzonite and quartz diorite to diorite	Epithermal vein, active continental margins, island arcs	0.3 to 1.5 g/t	Tertiary
6.	Polymetallic sulphide deposits	Calc-alkaline volcanic rock and pyroclasts, thin sedimentary oceanic accretion zones	Both in arc and ophiolite setting, stratiform, massive, stockwork	1.7 g/t	Precambrian, Tertiary
7.	Replacement deposits	Calcareous dolomitic pelite, psammites, black schists	Stratiform, bedded, epithermal, regional, extensional zones, normal, transcurrent faults.	Generally low	Palaeozoic
8.	Lode centred on intrusion	Monzonite	Vein type, terminal phases of magmatic intrusion	Variable	All ages
9.	Recent placers	Any auriferous primary rock	Eluvial, alluvial and buried placers, circumpacific border	Variable	Tertiary to Recent

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3. GOLD IN INDIA

The peninsular Indian shield provides the most potential environment for gold mineralisation and numerous primary gold occurrences are known. The South Indian shield is the richest of all and it has so far produced little over 850 t of gold. The Archaean greenstone belts (Dharwar schist belts) and analogous supracrustal enclaves in the adjoining late Archaean to Early Proterozoic high grade granulite terrain are the chief repository of gold. Nearly one hundred primary gold occurrences are known; but most of the gold have been produced from the schist belts of Kolar, Ramagiri and Hutti. Several new small gold prospects have been delineated in the vicinity of these three major mining districts. Most of the known deposits and some recently explored ones are epigenetic vein type which are amenable to underground mining. Disseminated and stratabound gold mineralisation hosted in exhalative sediments, small intrusions and banded iron formation (BIF) are the newer targets which hold considerable promise for becoming future resource of gold.

In Eastern India, gold was won from few scattered prospects in the past from Archaean as well as Early Proterozoic belts; the total recorded production is only around 220 Kg. A detailed review follows in the subsequent section. In Central Indian shield which is physically continuous to the Eastern part of India, epigenetic vein-type gold-sulphide-quartz mineralisation is known widely in volcanic host rock in the Proterozoic fold belts. A few prospects have been identified for detailed exploration. In western Indian shield, two new targets for gold have been identified during the course of recent exploration. In Extra-Peninsular India, epigenetic gold mineralisation in Proterozoic metamorphites and high level acid intrusives are known. Placer gold occurring all along the foothills of Himalaya is also of some importance as future resource.

4. GOLD ENVIRONMENT IN EASTERN INDIA

Ancient/old workings for gold on primary occurrences and recovery of native gold from streams and rivers in the states of Bihar, Orissa and West Bengal are well known. The very ancient Precambrian rocks are the source of gold.

(a) Geological set-up

The shield area of Eastern India stretches from the southern edge of Indo-Gangetic alluvium upto the northern half of Eastern Ghats granulite belt and covers an area of about 200,000 sq kms. It represents an assembly of diverse group of rocks with a protracted evolutionary history (3500 m.y. to 600 m.y.). Available stratigraphic, lithologic and radiometric data have indicated Singhbhum region, falling in parts of Orissa and Bihar, as representing one of the oldest Archaean cratonic nucleus (3400 to 3100 m.y.) (Saha et al, 1988). This is elliptical in outline with an area of over 10,000 sq. km. and comprises Older Metamorphic Group (OMG), Older Metamorphic Tonalitc Gneiss (OMTG), linear to arcuate greenstone belts (IOG) and Singhbhum granite. Bulk of the craton is composed of Singhbhum granite-a multi-component unit ranging in composition from tonalite to granite. The cratonic nucleus is flanked by weak to strongly tectonised Proterozoic successions (2500 to 2300 m.y.) of Jamda-Koira and North Singhbhum fold belt to the west and north respectively. The southern margin of the craton with the granulite belt appears transitional and as well as tectonic. Platformal lava-quartzite-conglomerate sequence of Dhanjori and Simlipal of Early Proterozoic age (2300 m.y) showing weak deformation and metamorphism rest on the cratonic nucleus to the NNE; east and possibly to the south-west. Still younger Early Proterozoic (2100 to 2200 m.y) sedimentary successions of Kolhan, Gangpur and Kunjor rest unconformably over the cratonic nucleus and Early Proterozoic supracrustal rocks. Some major granitic activities like Mayurbhanj and Soda-granite took place at the closing stages of the earliest early Proterozoic orogenies. The high grade granulite belt of Eastern Ghat occurring in southern Orissa and the Chotanagpur granite gneiss to the north of the Eastern India shield evolved during major thermal reactivation in Mid-Proterozoic (1600 to 900 m.y). The Late Proterozoic is marked by granite emplacement in northern gneiss complex. To the south of Mahanadi graben, parts of Bastar cratonic nucleus (3000 to 2600 m.y) of Central India fall in parts of south-western Orissa.

(b) Gold occurrences in Eastern India

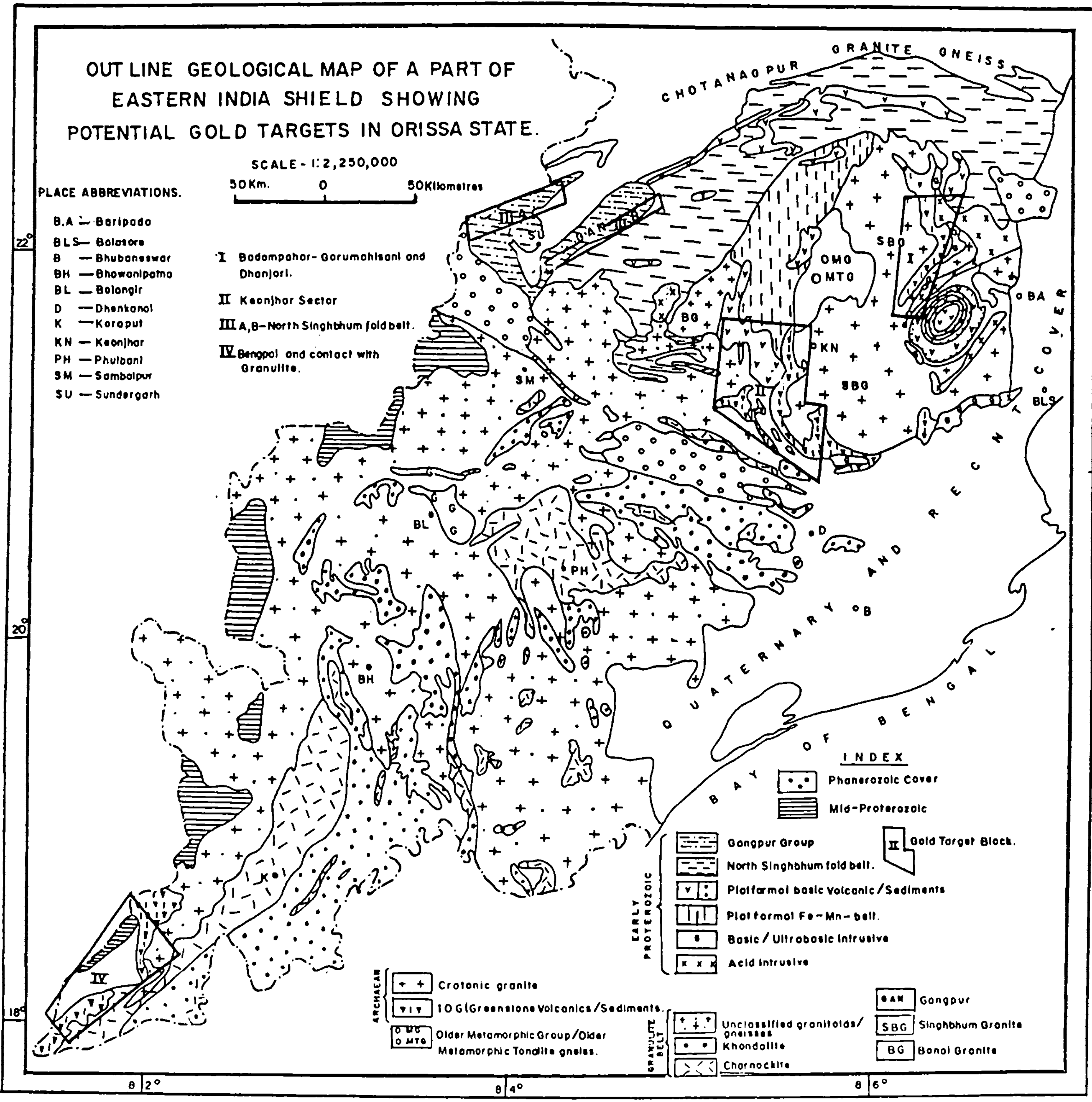
Within the above geological milieu, the primary gold prospects / occurrences can broadly be grouped into two chronologic units viz., Archaean and Proterozoic. The low-grade IOG comprising metavolcanic and metasedimentary rocks are found flanking the Singhbhum granite massif to the west and south and also occur as linear enclaves within the latter. At least some of the IOG rocks are akin to Archaean greenstone belts. The most important primary gold prospect of Singhbhum is the one occurring around Kunderkocha, Bihar, which returned 195 Kg. of gold and is located in the Mid-Archaean Badampahar - Gorumahisani Kunderkocha belt. The prospect is a typical vein type one with gold occurring only in a few rich shoots. Further southwest of Kunderkocha and in parts of Mayurbhanj district, several gold potential blocks have been delineated. To the southwest of Singhbhum granite several gold occurrences are located in volcano-sedimentary rocks. The occurrences are spread over a stretch of about 60 Km. and lie immediately to the south of Jamda-Koira (Fe-Mn) belt. This belt extends further south upto little north of Tomka-Daitari. In the eastern extension of Bastar craton, gold potentiality of Bengpal Group of rocks has been established and deserve systematic search.

In the North Singhbhum E-W trending fold belt of Bihar and West Bengal, a large number of prospects like Pahardia, Porhat, Monoharpur, Ankua, Sausal, Sonapet, Buruhatu, Ichagarh, Lawa and Myasara are known. Production record exists for only the last two prospects. Gold mineralisation is hosted in a variety of host rocks and is largely structurally controlled in ductile - brittle shear zones (DBSZ). The basal Dhanjori sequence has shown gold potentiality in Quartz pebble conglomerate (QPC). Sporadic gold occurrences in the Chotanagpur granite gneiss terrain are reported. A summarised account of the Chronostratigraphy, type of gold mineralisation and prospect of Eastern Indian shield are shown in Table - II. Eluvial and alluvial placer gold occurrences are widely known from Singhbhum district of Bihar, Purulia district of West Bengal and from most of the northern districts of Orissa. Rare gold nuggets weighing few tens of grams were reported from some localities. However, the work carried out so far has not indicated the economic potentiality for large-scale exploitation of these placers.

5. GOLD IN ORISSA - AN UPDATE

Based on the existing concepts of space-time relationship of various gold deposits all over the globe and more importantly on empirical geological criteria such as rock association, age, tectonic setting, depositional environment, geochemical association and abundances, the principal terrains for identification and delineation of gold targets are: (1) Badampahar - Gorumahisani belt, (2) Tomka-Daitari to further north-west upto south of Jamda-Koira valley, (3) possible Archaean greenstone in Bonai craton, (4) Bengpal Group, granitoids and the contact zone with Eastern Ghat granulite, and (5) Early Proterozoic successions of Gangpur/Singhbhum Group and basal Dhanjori. Fig-1 is an outline map of Orissa showing potential areas for gold occurrences.

The Archaean greenstone belts are prodigiously rich in gold deposits all over the world and naturally these constitute the prime targets in cratonic blocks of Orissa. The Singhbhum craton hosts the Mid-Archaean Gorumahisani - Badampahar schist belt (IOG) composed of basic-ultrabasic volcanic rocks and volcanogenic sediments. These low metamorphic grade rocks are highly deformed with major N-S trending upright folds. The schistose rocks occur in linear synformal strips and are arcuated by intrusive domal granitoids of Singhbhum and Mayurbhanj granite. Preliminary to advance prospecting in various stages are in progress in this belt. This belt has been prognosticated as a rift-type of volcanic - dominated one and is highly potential for economic grade gold mineralisation. Likely targets include. (a) auriferous quartz veins close to the contact of sulphidic chert-volcanics, (b) sheared and sulphidised Fe-rich tholeiite with anomalous copper, (c) epigenetic vein type of mineralisation in BIF-volcanic association and (d) sulphidic conglomerate resting over the basic volcanics. (QPC type).



OUT LINE GEOLOGICAL MAP OF A PART OF EASTERN INDIA SHIELD SHOWING POTENTIAL GOLD TARGETS IN ORISSA STATE.

Modified by the author after Misc Pub No. 30, G.S.I., 1974

Table - II East Indian Shield

Age in m.y.	Chronostratigraphy	Type of mineralisation	Prospect
600			
	Granite emplacement in Chotanagpur granite gneiss complex.		
900			
	Major thermal reactivation in Chotanagpur granite gneiss, Charnockitisation in Eastern Ghats.	Minor Quartz -vein in enclaves of Chotanagpur gneiss, Also gold in association with polymetallic sulphides	Needs further testing
1600			
	Kolhan Group Gangpur Group (metasedimentaries)	Minor vein type.	Poor
	Mayurbhanj-soda granite-basic-ultrabasic plutons		
	Dhanjori Group, Simlipal (Quartzite + Lava)	Basal QPC, sheared acidic rock	Geochemical gold anomaly located.
	Singhbhum Group (Pelitic -arenaceous sed. - mafic sills, central volcanic)	Quartz vein in DBSZ in volcanic and arenite, algoma-type BIF (disseminated gold sulphide)	Old gold prospect/ working exist.
2500			
	Younger Iron Ore Group (Quartzite-lava-Fe-Mn-sediments)		
3000			
	Singhbhum Granite - III Volcanosedimentary belt of Eastern and Southern Singhbhum (Older Iron Ore Group)	Quartz vein in schistose units and are structurally controlled, QPC	Old gold prospects exist, strata-bound gold in supractustal rocks and intrusive hosted epigenetic veins likely. Many occurrences known.
	Bonai, Singhbhum granite I & II.		
3500			
	Older Metamorphic Group		

Many of the workers have correlated other BIF-bearing supracrustal belts occurring in the fringe areas of Singhbhum granite batholith with the Gorumhisani - Badampahar belt. Thus it has been opined that the BIF-volcanic belt of Gorumahisani - Badampahar, Notto-Boula (Hadgarh belt), Daitari and Malyagiri are a continuous one and are all older than 3100 m.y. (Iyenger & Murthy, 1982, Banerjee, 1974, Chakraborty & Mazumdar, 1986). However, it is observed that the axial traces of major folds in these belts curve round the cratonic massif of the Singhbhum granite which tend to suggest that the folds in the supracrustal rocks were moulded round the rigid basement (?) block. Therefore, the stratigraphic status of all these BIF - volcanic (± sediments) association except the Gorumahisani - Badampahar belt relative to Singhbhum granite remain controversial. These may as well be Late Archaean to Early Proterozoic in age. Alternatively, they may represent assembly of rocks of diverse ages. Recent investigation in the south-west and south-southwest of Keonjhar have revealed placer gold shows little over 2,000 sq. km. of area. The area represents mixed volcanic and clastic sediment dominated sequences with NW-SE trend of uncertain age. Subaerial to subaqueous mafic volcanic rocks, conglomerate, arenite and oxide facies BIF are the major rock units which show rapid facies variation and are intruded by sub-volcanic acidic rocks, quartz vein and late basic / ultrabasic plutons. The rock types show low grade metamorphism, weak deformations and are cut by longitudinal and oblique faults/shear zones. They bear resemblance to pull-apart basins and are likely to host detrital gold in platformal assemblage and lode gold deposits in volcano-sedimentary pile and related plutonic rocks. This assemblage is bounded to the north-east by Singhbhum granite and to the south-west by a major NW-SE trending shear zone (Malyagiri shear). To the south-west of the shear zone, a folded medium grade sequence of metapelite-quartzite amphibolite-BIF constitute another potential gold target. The low grade supracrustal rocks lying to the north-east of Malyagiri shear passes on to BIF-metabasite assemblage further south-east into Tomka-Daitari area. Gravity survey in certain parts of this belt has indicated considerable thickness of basic rocks occurring in a narrow linear strip. Apart from the primary targets, potential secondary targets include laterite and Quaternary gravel beds in this terrain.

The Bengpal Group and associated granitoids of Koraput district constitute an Archaean granite-greenstone terrain. The eastern boundary of this terrain with the adjoining Eastern Ghat Mobile Belt (granulite facies) appears highly tectonised and the contact zone is intruded by anatectic granites. It is possible that greenstone screens may extend into the high grade terrain just as the case in Southern Indian shield. Native gold of very high fineness are abundant in the area and some quartz veins in the contact zone have indicated gold value in ppm. level. The area merits thorough prospecting. Recent GSI's work on Bonai granite occurring in the western part of Singhbhum craton indicates the former to be a composite batholith of 3.2 b.y. of age. This granite is intrusive into basic-ultrabasic greenstone occurring as downfolded synclinal remnants and thus, the latter is potential for hosting gold mineralisation.

Placer gold shows in the drainage from the Lower Proterozoic fold belts of north-west Orissa and adjoining M.P. State also deserve attention for delineation of precise target areas, if any. Towards north-east Orissa, the basal part of Dhanjori basin also deserves to be looked into.

Placer gold occurrences are known from rivers and streams draining mostly the northern districts of Orissa, such as Dhenkanal, Keonjhar, Mayurbhanj, Sundargarh and Sambalpur. However, most of these occurrences are generally small, widely separated with low incidence of gold. In Mayurbhanj district, an area of about 5 sq.km. of alluvium at the headwaters of Sapgora and Borai rivers near Kudersai was indicated as promising (Bose, 1904). Nuggets weighing upto 5.6 grams was found in brownish alluvium of 60 cm. thickness. In the nearby Gohaldongri area, nuggets weighing between 23.25 to 31.1 grams were obtained from a gravel bed. Extensive placer gold shows in gravel beds are known in several parts of Koraput district.

Results of exploration

During the last one and half decades, investigation for gold has been carried out by Geological Survey of India (GSI) and Directorate of Mining and Geology (DMG), Government of Orissa in various parts of Orissa. Following is an abridged account of the results obtained so far by GSI, DMG and the author's own field assessment.

(1) The Mid Archaean Badampahar -Gorumahisani belt, Mayurbhanj district has been covered by thematic mapping and regional stream sediment survey. This resulted in identification of nine blocks for follow-up survey (GSI). Exploration carried out in some of the blocks has indicated rather lean mineralisation with gold values ranging from trace to 2g/t over narrow width. However, some significant geochemical anomalies for pathfinder elements like Cu and As have been obtained in some blocks. Test sampling of quartz veins hosted in schistose volcanics returned poor values in northern part of Gorumahisani (DMG). In Sulaipat area, systematic sampling of a 2.3 km long pyrite-bearing and uraniferous polymict conglomerate horizon resting on volcanics indicated low gold values (0.1 to 0.8 g/t). Only one sample yielded 1.9 g/t.

Smoky and cherty looking quartz veins, the principal host for gold ore, are emplaced along the prominent schistosity planes of the metabasites (actinolite - chlorite - albite - quartz schist), tremolite-chlorite schist, cherty phyllite and banded chert. Generally the quartz veins are narrow, stringery and impersistent and their strike vary from N-S to NW-SE to E-W and NNE-SSW with moderate to steep dip to east and north following the swing of the regional schistosity. Perhaps they represent ribbon quartz in ostensibly sheared volcanic and volcanogenic sediments. Silicification and greenschist facies alteration like talc, chlorite, serpentine around such mineralised quartz veins are noticeable. Pyrite is the commonest sulphide in such zones and locally chalocopyrite is also noticeable.

(2) The Precambrian volcano - sedimentary sequence occurring to the southwest and south-southwest of Keonjhar has been prospected by DMG. Most of the quartz veins and the old workings have been sampled and one prospect at Gopur was tested by 8 boreholes. Economic grade gold values (3 to 8 g/t) were found to be patchy and impersistent. The prospect is under active exploration. Systematic regional stream sediment survey and mapping led to the identification of some blocks for follow-up exploration. The primary geological targets include QPC type with uranium - thorium and quartz veins in schistose units in the vicinity of major structural lineament. Secondary targets include auriferous laterite and Quaternary gravel beds. Secondary gold shows in the stream are perhaps most widespread in the area. It has been observed that gold is being shed from multiple sources.

A paleoplacer zone located about 10 kms north of Telkoi and 3 kms NNW of Saleikana has been identified. This appears to be a potential block for secondary gold mineralisation (Singh et al 1994). Also it can, reasonably be inferred that mobilisation, reprecipitation and enrichment of native gold in the partially truncated deep weathering profile and their subsequent erosion and reprecipitation in secondary collector beds have contributed considerably to the surficial spread of gold shows.

Auriferous quartz veins are massive as well as brecciated, concordant to foliation and tend to occur in parallel sets in schistose to phyllitic host rock of both volcanogenic and sedimentary parentages. The veins contain disseminations of pyrite and chalcopyrite. En-echelon pattern, branching, pinch and swells are characteristics of the veins. Their strike vary from NW-SE to NE-SW with moderate to steep dip. Chloritic and argillitic alteration adjacent to the veins are common.

(3) Preliminary sampling in parts of Koraput district indicated auriferous nature (around 1 g/t Au) of some of the quartz veins hosted by Bengpal Group of rocks. The area merits systematic search for vein-type and intrusion hosted gold mineralisation.

(4) Preliminary sampling in parts of Gangpur Group of rocks did not indicate any gold value in the quartz veins although placer gold shows are present in the area.

In summary it may be stated that barring two major belts as indicated in (1) and (2) above, systematic search for gold is yet to be taken up in many other potential areas.

6. CONCLUDING REMARKS

Rocks belonging to Archaean era and exposed in the cratonic blocks of Singhbhum, Bonai and Eastern Bastar are quite abundant in Orissa. These and some other Proterozoic belts are highly potential for locating economic-grade gold mineralisation. There is a need for mounting effective and efficient exploration programme for gold in Orissa state. The following strategies are suggested.

(1) Appreciation of concepts of metallogenesis in regional and local context.

(2) Increasing utilisation of remotely-sensed data such as multisensor airborne survey, space imageries etc.

(3) Regional stream sediment surveys with modern systematics and adequate back-up instrumental multi-element analysis.

(4) Intensification and projectisation of exploration in already identified blocks.

(5) Extensive exploration and thoroughness of search may be necessary in view of geological diversity.

(6) Testing of unconventional targets based on recent concepts of gold metallogeny.

(7) More aggressive sampling and speedy analysis by technical experts in the field of gold exploration.

(8) Persistent and repeated examination of potential blocks by the application of alternative genetic concept.

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Graphite

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1. INTRODUCTION

Natural graphite is an allotrope of elemental carbon which crystallises in the hexagonal system. The name is derived from the Greek word "Graphien" meaning to write. It is a soft and opaque-black mineral with a metallic lustre, greasy feel, hardness of 1 to 2 in Moh's scale, specific gravity of 2.09 to 2.93, anisotropic in its physical and mechanical properties and has a weak plane of cleavage parallel to the lamellae. A good conductor of heat and electricity, it has high refractoriness and can withstand temperature upto 3000°C in an inert atmosphere. In the presence of oxygen, it burns between 620°C and 720°C. It remains unaffected by most of the acids and reagents but yields graphitic acid on treatment with a mixture of potassium nitric acid.

Although occurrence of graphite in the State was reported by Walker as early as 1902, systematic study of the graphite occurrences in the State was taken up by the GSI. from around 1941 in the course of geological mapping and has been continuing intermittently since. The Directorate of Mining & Geology initiated systematic investigations since 1970s. Sporadic surveys had been carried out by the DMG during the 1960s.

2. GEOLOGY AND ORIGIN OF GRAPHITE

Origin of graphite, in particular, poses three diverse types of problems, namely - source of carbon, graphitisation or mechanism of conversion of carbon to graphite and localisation leading to deposits of graphite. The metasedimentary bedded deposits originating from biogenic carbon in sediments have a rather simple process of origin because source is easily discernible, graphitisation is by metamorphism and localisation is in situ. However, the problem is different in igneous rocks because the miscibility of carbon and its compounds in igneous melts is questionable. The vein type deposits have further and much more complicated problems because the physico-chemical characters of graphite point to high temperature of formation whereas these veins represent low pressure-temperature hydrothermal fracture-fillings. The most important graphite deposits of India belong to the vein-type occurring in Precambrian migmatitic rocks.

The fact that graphite occurrences are related to the structure and lithology of the country rocks has been noticed by many workers. Association of graphite with metasediments as well as pegmatites has been observed.

A good deposit may be located where metasediments associated with calc-silicate granulite are permeated with quartzo feldspathic neosomes and/or where such metasediments have favourable structural sites like foliation, fold hinge, boudin necks, joints etc. A peculiar structure-cum-lithological feature is the "intrusive breccia" resulting from graphite-mixed breccia near fault zones.

The fabric of the graphite-bearing parts of the country-rocks point to emplacement of graphite by filling of open spaces under conditions of low pressure.

Another microfabric feature of great genetic significance is the intergrowth between specks, scales and masses of graphite with calcite, chlorite, biotite and sericite. This is indicative of chemical relation between graphite genesis and breakdown of calcite with consequent development of the associated minerals. Calc-silicate granulite relics are present within graphite-bearing pegmatite. Calcic plagioclase, calcite, tremolite, epidote and sphene in such graphite-bearing pegmatite also point to interaction between calc-silicate country-rock and pegmatite emplaced into it. Feldspar and biotite of such pegmatite contain irregular inclusions of graphite and calcite, often with corrugated margins corresponding to unreacted pitted surfaces of calcite resulting from synthesis of graphite and hydrocarbons by reaction between calcite and hydrogen. Evidence that graphite formation was associated with metasomatism and migmatisation is provided by textural features such as presence of graphite particles in reaction rims of chlorite around calcite. Such reacted calcite grains are present as inclusions within biotite occurring in pegmatite intruding calc-silicate granulite. Symplectitic intergrowths between plagioclase and calcite and inclusions of calcite in plagioclase further suggest replacement of the carbonate by the neosome material. Similar microscopic association of graphite with tourmaline, lepidolite, sericite etc. confirm the role of metasomatism in formation of hydrocarbons from carbonate.

The microfabric of graphite itself suggests remobilisation in solid state after the formation of graphite. As for example, flakes and tablets of graphite are curved at places although the gangue minerals show no evidence of folding. Translation of graphite along (0001) plane is evidenced by slipping-off, stepping, splintering, kinking and branching. Breccia-like admixture of graphite and gangue minerals are also frequent around graphite deposits.

Graphite mineralisation in Orissa is confined to Khondalite group and its migmatised variants belonging to the Eastern Ghats Supergroup of Archaean. Pegmatites, sometimes thought to be source of graphite, in effect provide low pressure sites at their margins, cooling joints and coarse grain boundaries at which pyrolysis of hydrocarbons is facilitated. The heat required for methanation of carbonates might have been supplied by the pegmatites.

The structural and lithological sites as well as the microfabric and mineralogical features of both uneconomic and economic occurrences of graphite in Eastern Ghats migmatite complex assessed against the data on rock mechanics and thermodynamics do not lead to any singular solution for the origin of graphite in these rocks. A dominantly sedimentary or igneous parentage of carbon can not be attributed here, although some graphite may be of these origins. Calcium carbonate in the calc-silicate granulite is proposed to be the main source of hydrocarbons (methane or butane) which were graphitised by pyrolysis at sites of low pressure. The main mechanism of development of graphite lodes is proposed to be solid state migration (remobilisation) of graphite through open spaces in the host-rocks due to translation along (0001) planes in graphite. Such translation is a very common character of graphite. The low pressure sites include structural sites, pegmatite contacts, coarse grained neosomes etc.

3. GEOLOGICAL GUIDES FOR EXPLORATION

What is important regarding exploration is that the distribution of graphite in Eastern Ghats migmatite complex does not follow any single set of geological controls. On the contrary, it follows coincidence of several sets of controls like - low pressure sites dependent on rock structure, grain size, fabric etc., chemical sites dependent on metasedimentary (calc-silicate granulitic) lithology and metasomatic replacement sites like quartzo feldspathic pegmatites and neosomes. Size-shape variations, graphite concentration, quality, etc. depend on the mode and intensity of such control-coincidences. That, probably, is the reason of vein-type graphite deposits being so sporadic as they are.

The following geological guides are significant parameters of graphite localization :

A. Structural

1. Foliation, banding, axial plane, joints, fault.
2. Lithologic margin, pegmatite margin, boudin margin.
3. Fold hinge, boudin neck.

B. Lithological

4. Metasediments associated with calc-silicate granulite.
5. Pegmatite, quartzo-feldspathic units.
6. Intrusive breccias.

C. Textural

7. Coarse grain size (of the recrystallised palaeosomes and the neosomes),
8. Microshears, cleavages, kinks favouring remobilisation.
9. Metasomatic replacement sites at quartzo- feldspathic neosomes (zones of micro-intergrowths)

Geophysical methods (EM, SP, magnetic) are useful for reconnaissance and targeting possible lodes. Deep pitting and drilling have to be undertaken for proving. But geological guides are necessary for all intermediate purposes like detailed interpretation of geophysical data, finalisation of drill sites, mine-site specification, mining method choice etc.

4. EXPLORATION

During the 1980s, Geological Survey of India and the Directorate of Mining & Geology carried out detailed investigations in the undivided districts of Koraput, Kalahandi, Bolangir, Sambalpur, Phulbani and Dhenkanal in accordance with the programme finalised in the meetings of the State Geological Programming Board on annual basis.

While the exploration activities of the GSI have been confined to parts of undivided Bolangir, Sambalpur and Phulbani districts, exploration activities of the DMG have been by and large confined to Koraput district. During the period 1984-90, exploration inputs by the GSI comprised 800 Km^2 of area targeting, 624 Km^2 of detailed geological mapping, 288 Km^2 of geophysical prospecting (SP, EM and magnetic), 472 m^3 trial excavation, over 9000 meters of drilling in as many as 326 bore holes, collection and processing of over 900 samples for analysis (proximate and complete).

5. RESERVE

The grade-wise break up of recoverable reserve of graphite in Orissa as on 1.4.90 is estimated to be as follows (Basis : Indian Minerals YearBook 1993).

+ 40% FC*	151,000 tonnes
10-40% FC	640,000 tonnes
Unclassified	127,000 tonnes
Not known	16,000 tonnes
	934,000 tonnes

* Fixed Carbon

The total recoverable reserves in India are placed at 3.1 million tonnes as on 1.4.90.

On the basis of exploration carried out by the GSI, the following reserves have been estimated

1.05 million tonnes with 13.7% average FC at 5% FC cut-off and within a depth of 30 m.

0.86 million tonnes with an average 14.6% FC

The DMG has estimated a reserve of 0.55 million tonnes in Koraput district. Thus, it would appear that the total reserve in the State exceeds the reserve inventoried by I.B.M as on 1.4.90.

6. GRAPHITE CHEMISTRY

Basically, a non carbonate carbon, graphite has the following constituents in the raw state.

Ash (Mineral matters)	59 to 88%
SiO_2	27 to 47%
FeO	1 to 15%
Al_2O_3	15 to 29%
CaO	0.56 to 3.9%
MgO	0.80 to 40%
Loss on Ignition	12 to 40%

The range of phosphorous is usually from 0.04 to 0.20% and iron from 4.9% to 9.5%. Manganese is not usually seen to exceed 0.13%. Clay bands and biotite form the common gangue mineralogy.

Some important trace elements from stream sediments of rivers draining the graphite deposits analyse up to V 63 ppm, Ba 69 ppm, Pb 11 ppm, W 24 ppm (often <10 to 100 ppm)

7. PARTICULATE PROPERTIES AND PHYSICO-CHEMICAL ATTRIBUTES

Graphite is mostly flaky with flake size of 20 to 200 #. Specific gravity remaining constant, the bulk density of graphite varies from 1.72 to 2.75 depending mostly on particulate dimensions (smaller the grains, higher the bulk density and vice versa) as well as bivalent - trivalent cations like CaO + MgO + Al_2O_3 + Fe_2O_3 (higher the cation, higher the bulk density and vice versa). Neither the Fixed Carbon nor the silica content has any direct effect upon bulk density of graphite.

Graphite with 150 to 180 micron grain fractions have a special affinity towards tungsten where it rises upto 0.02% (WO_3). However, overall tungsten content from Orissa graphites is low, below 100 ppm of WO_3.

8. OCCURRENCES

The major graphite zone of Orissa is coincident with the migmatised quartz-garnet -sillimanite-graphite schists of Khondalite suite and its contact with medium-grained granite gneiss. The geomorphological features are characterized by an old age of denudation manifested in mildly undulating topography with gentle slopes on the pediments of mostly lateritised sub-horizontal pediplains. Broad dendritic drainage is the overall pattern while gullies and/or sheet erosion features, often indicate buried deposits, through structural reflections of the weak zones e.g. folds, faults, foliations and thence the localization of mineable graphite bodies. Associated quartzites and calc-silicate rocks too harbour occasional graphite bodies. Fig. 1 depicts the general geology of the graphite belts. The important graphite belts of the State, are :

Sargipalli	2,240 sq.km	21°00'-22°22' and 83°15-83°40'	Main workings at Sargipalli, Dangachancha,
Bargad , Bolangir & Kalahandi districts	More than 150 occurrences		Darrhamunda, Sapmuna, Dharukhaman, Rengali, Mohanilah, Raju-Nagfena and Benimal occurrences.
Titilagarh belt,	3,500 sq.km	20°06'-21°24' and	Prominent quarries are near Titlagarh, Boroni, Malisira
Bolangir and Kalahandi districts	Around 120 Occurrences	83°00-83°35'	Singjharan, Loitora
Tumudibandh belt	9,600 sq. km	18°45-20°00' and	Main workings at Tumudibandh
Phulbani, Rayagada & Gajapati districts	more than 50 occurrences	83°00-83°45'	Lakhajorna, Palur, Raisil, Ambaguda.
Dandatopa belt	1,000 sq.km	20°37' -21°00 and	Prominent quarries are at Dandatopa, Adeswar,
Dhenkanal and Angul Districts	22 occurrences	84°15'-84°45'	Kamalpur, Akharkata, Girida

Fig. 2 is an outline map of Orissa showing Graphite belts.

Graphite mineralisation of interest has been recorded at the contact of khondalite with granite gneiss in some locations in Athgarh sub-division of Cuttack district.

FIG.I GENERAL GEOLOGY OF THE GRAPHITE BELTS OF ORISSA

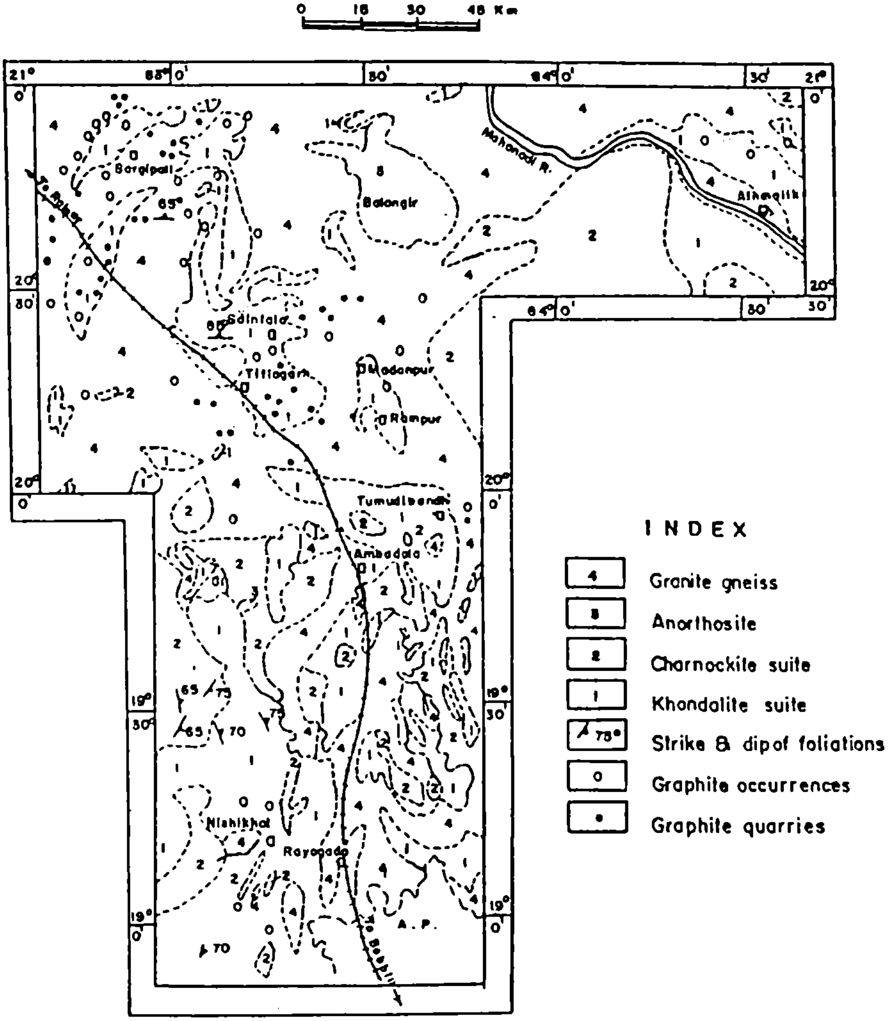
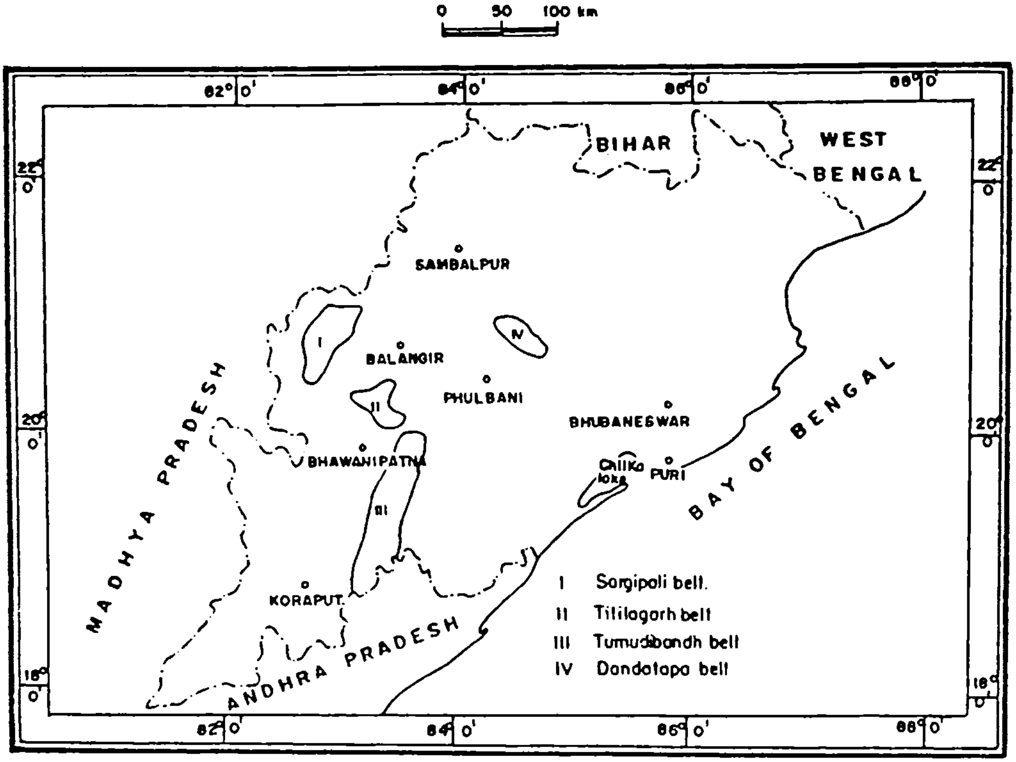


FIG.2 MAP OF ORISSA SHOWING GRAPHITE BELTS



Geographically, the graphite deposits in Sargipali, Titlagarh and Tumudibandh belts are clustered more or less in western to north-western parts of the Eastern Ghat hill ranges but the Dandatapa belt is an isolated and small zone lying to north of the Mahanadi lineament. The major graphite output however has been the Sargipali and Titlagarh belts on date.

The occurrences can be classified under the following types :

1) Disseminated and streaky
2) Banded and lensoid
3) Vein, stringer, schliern types
4) Sheet type and
5) Pockety type

The disseminated flakes (20 to 1,500 microns dia.) are occasionally even upto 30% in graphite schists. The band / lens type of ore bodies, 300 to 500 meters long and 5 to 6 m wide; conformably disposed as interbands or en echelon partings, often form the most preferred mining ventures. Graphite veins commonly epigenetic, are hardly economic for exploitation unless are found together with irregular but sheeted deposits howsoever thin. Pockety deposits go with the pegmatite aureoles within the graphite schist country rock or occasionally the carbonaceous shales of the Gangpur rocks. Most of the deposits occur usually in 3 to 10 parallel / subparallel pay lodes, distributed within local traps; structural stratigraphic or mixed.

9. MINING, PRODUCTION AND BENEFICIATION

There are as many as 120 recorded mining leases in the State, the lease areas ranging from less than one hectare to 100 hectares. District-wise break-up of mining leases is as follows :

District	No. of Leases	
Angul	2	(Nil)
Bargad	29	(17)
Bolangir	57	(39)
Boudh	1	(Nil)
Kalahandi	20	(8)
Koraput	1	(Nil)
Phulbani	3	(1)
Rayagada	7	(3)

(Figures within brackets indicate number of leases in operation)

On account of sporadic occurrences and small reserve, the mining operations are all opencast, manual to semi-mechanised and confined to depths of within 30m. The only underground mine at Sargipali in Bargad district which commenced production during 1943, is no more operative. Madaguda graphite mine of M/s T.P. Mineral Industries near Tumudibandh in Phulbani district is the only opencast mine where some degree of mechanisation has been resorted to on account of banded nature of ore body of 30 m average width and exposed strike length of about 150m. The mine is being worked in 1.5m high benches and the maximum depth attained is 35m.

Production of graphite in the State has remained static at a level of around 74,000 tonnes. The grade-wise break-up of production during the last three years has been of the following order :

(in tonnes)

		1991-92	**1992-93**	**1993-94**
+ 80%	FC	-	-	-
+ 40%	FC	2,335	6,159	4,602
+ 20%	FC	11,195	6,056	5,023
- 20%	FC	59,513	62,724	64,363
Total	**73,043**	**74,939**	**73,988**	

Almost all the r.o.m. graphite produced are beneficiated to marketable grades conforming to the specifications of the consuming industries. The common beneficiation steps adopted include primary crushing of r.o.m. graphite, secondary crushing, froth flotation (using pine oil, kerosene etc.), drying, sizing and pulverisation. The FC contents of r.o.m. graphite processed range from 8% to 30%. Graphitic material containing as low as 6% FC has also been successfully beneficiated. Depending on the desired FC in the product, the flotation process is repeated. The final grades are upto 90/95% FC. Further enrichment can be accomplished by chemical treatment. The size range of the beneficiated products conforms to the following :

-20 + 50 BSS	Large flakes
-50 + 100 BSS	Medium flakes
-10 BSS	Fine flakes

The graphite powders produced conform to the following range

ISI	Gr. I	85% FC
	Gr. II	75% FC
	Gr. III	65% FC

Size -200 BSS, minimum 80% passing

There are 24 beneficiation plants in the State, distributed in Bolangir (11) Kalahandi (1), Rayagada (4), Phulbani (1), Puri (1) and Sambalpur (6) districts. Of these, 20 plants are in operation. The r.o.m. throughput capacity of the plants ranges from 100 to 1000 tonnes per month. In some of the plants, facilities exist for manufacture of crucibles. Medirattes were the first to manufacture Si-carbide crucibles in their plant at Titilagarh.

The graphite mining and beneficiation activities in the State are entirely with private sector.

10. INDUSTRIAL USES AND SPECIFICATIONS

The term "amorphous", when applied to graphite, is a misnomer. All graphites are crystalline, but the type commonly known as amorphous is extremely fine-grained and can be appropriately called "micro-crystalline." Crude graphite seldom finds direct application in industry. It is invariably beneficiated to produce the required quality. Its principal industrial uses are as crucibles and foundry facings; lubricants, in brake linings, pencils, electrical and motor brushes, paints, polish, rubber, explosives, batteries. Natural graphite powder has also been used in powder metallurgy applications. Graphite is used to raise the carbon content and thereby hardening of steel. An important use of graphite in steel making is as carbon-magnesite bricks. Crucibles, refractories and foundry facings account for about 80% of the total industrial uses of graphite.

The Bureau of Indian Standards has prescribed specifications for different end uses of graphite. These are :

Crucibles	IS 11321	1985
Foundry facings	IS 305	1984
Lubricants	IS 495	1967
Paints	IS 62	1950
Wooden Pencils	IS 2079	1982

The refractory manufacturers in India require graphite with 80 - 95% FC and 4.3 to 20% ash. The following four grades have been specified by the Sub-Committee on Refractory Raw Materials appointed by the DGTD (1985).

	Grade I	**Grade II**	**Grade III**	**Grade IV**
% FC (min)	95	90	85	80
Fusion Point of Ash (°C)	1,550	1,550	1,400	
Physical	Flaky with - 40 to -60 mesh size			

Regardless of BIS specifications, the foundries have been using graphite with even 40% FC. However, the standard grades are with +65% FC.

For the purpose of royalty, graphite has been classified into the following grades. :

a) With 80% or more FC
b) With 40% or more FC but less than 80% FC
c) With 20% or more FC but less than 40% FC
d) With less than 20% FC.

11. DEMAND AND AVAILABILITY

The indigenous demand of graphite by various end users has not been exactly estimated largely due to the unorganised nature of the industry. The entire demand of natural graphite was until recently being met by domestic producers, which is roughly estimated at around 15,000 tonnes per annum. Between 1978 and 1991, India exported graphite to countries like U.K, U.S.A., Japan, Taiwan, Thailand among others. The scene has changed with the entry of China and Canada. The domestic producers have been further handicapped by reduction in import duty from 105% to 50%, facilitating marketing of Chinese and Sri Lankan graphite at the cost of the domestic producers.

12. GENERAL REMARKS

Graphite mining industry is constrained on account of limited reserves distributed in large number of leases and locations in traditional non-mining areas lacking basic infrastructure facilities. The infrastructural deficiencies which include roads and power supply call for remedial measures.

The resource base is highly suggestive of augmentation considering the vast unexplored granulite terrain with favourable geological setting. The current exploration programmes of the GSI. and DMG should therefore be continued and sustained.

Quite a few mines have been abandoned within shallow depths due to water seepage and need for dewatering at some cost. A number of mines have been worked unsystematically. All such mines could be reopened with proper dewatering arrangements, safe and scientific mining practices.

Liquid effluents from beneficiation plants and wash off from mines should be properly treated to prevent possible pollution to the water courses. The domestic producers should be protected against imported graphite by appropriate rationalisation of the import duty.

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Iron Ore

B.K. Mohanty
Former Director of Mining & Geology,
Government of Orissa

1. INTRODUCTION

Iron is a very important element comprising about 5% of the earth's crust. It is rarely found in native condition except in the meteorites and eruptive rocks in association with cobalt and nickel.

Although a large portion of common ore and rock forming minerals contain appreciable amounts of iron, the source minerals from which iron is being extracted on commercial scale, are only a few. These are essentially oxides, hydroxides and carbonates of iron and include the following :

		Fe content
Hematite, Maghemite, Martite	Fe_2O_3	69.9%
Magnetite	Fe_3O_4	72.4%
Goethite (Limonite)	$Fe(OH)_3$	62% ±
Siderite	$FeCO_3$	48.2%

The ore minerals do not occur in pure form, contain varying amounts of silica, alumina, phosphorous, sulphur among others. Hence, the ore minerals contain less than the theoretical maximum values of iron. As the iron content in the crude (run of mine) ore being mined in different countries varies over a wide limit (20 to 68%), the r.o.m. ore has necessarily to undergo some sort of processing and beneficiation before its use. In Orissa, the minimum iron content of ore that is being mined at present is around 58% and it is essentially hematite with minor proportion of goethite.

2. HISTORY OF EXPLORATION AND MINING

The earliest record of exploration in the State dates back to 1904 when late P.N. Bose discovered iron ore deposits in Gorumahisani and Badampahar in the erstwhile princely State of Mayurbhanj (now Mayurbhanj district). Gorumahisani deposits were investigated by Perin & Weld (1905), Curnow (1914-15), Judd (1915), Dhar (1933-41) and B. D. Upadhyay (1961-62). The investigation of Badampahar deposits was mainly carried

FIG. I REGIONAL GEOLOGICAL MAP OF BONAI - BARAJAMDA- KEONJHAR - GANDHAMARDAN - DAITARI AREA

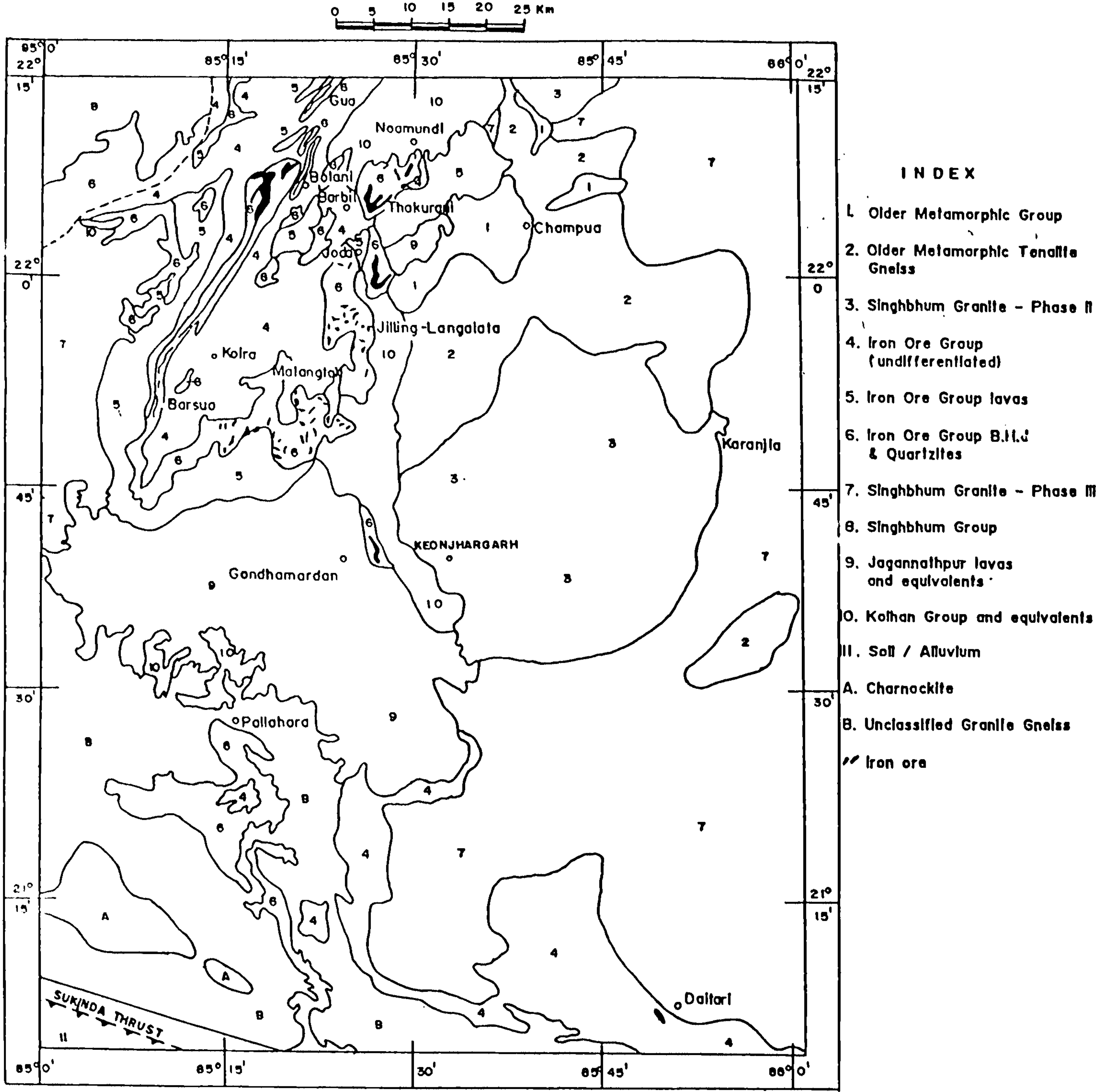
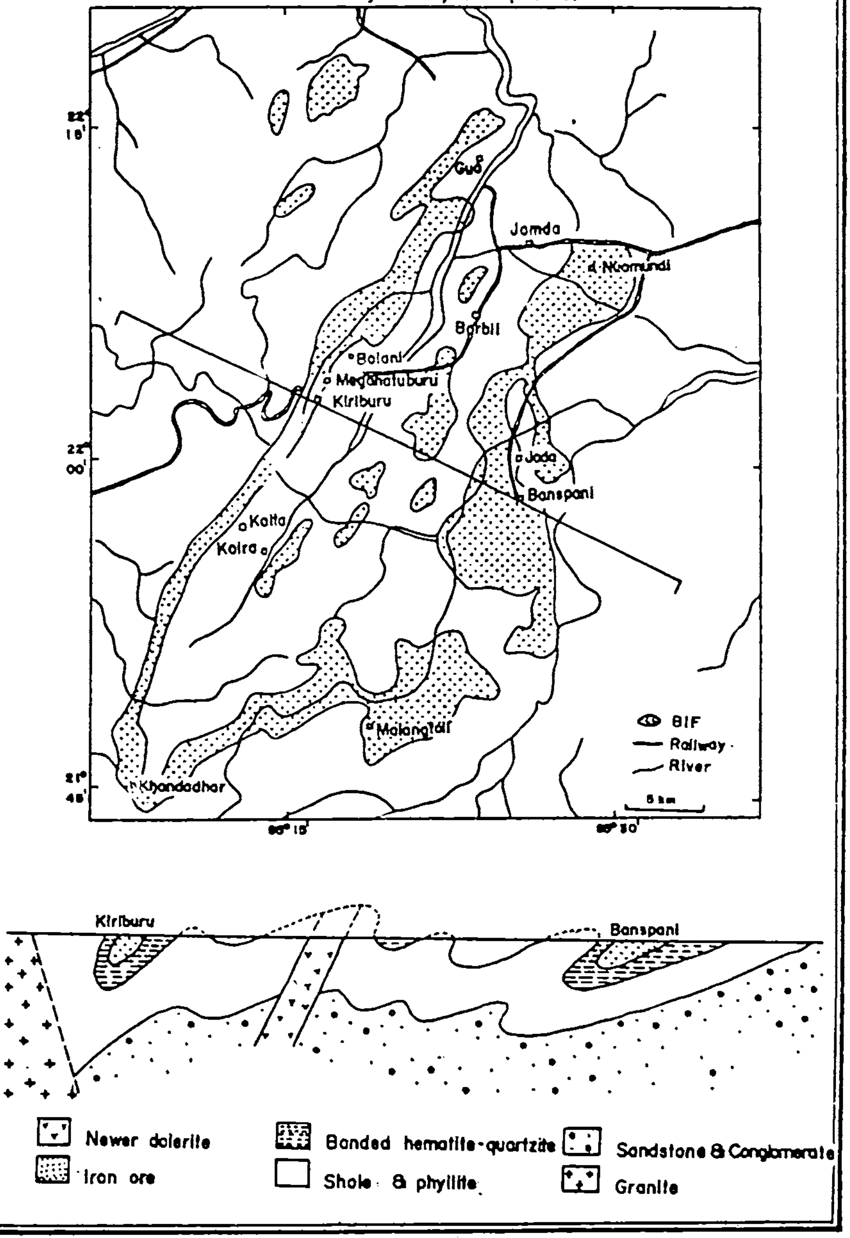


FIG. 2 SKETCH MAP OF BIF DISTRIBUTION AND GEOLOGICAL SECTION IN SINGHBHUM (BIHAR) - KEONJHAR (ORISSA) DISTRICTS

(Chakroborty & Majumder, 1986)



out by Narke (1915), A. K. Bose (1921), Dr. Percival (1922), B. Sen (1937), Dhar (1937-38) among others. Mining started in Gorumahisani during 1911-12 which along with Badampahar and Sulaipat constituted the source of iron ore for the Iron & Steel works of Tata Iron & Steel Co. Ltd. at Jamshedpur. The existence of rich deposits of iron ore in the erstwhile State of Kendujhar was brought to light by Frederick Dundes Whiffin, the then Manager of Bengal Trading Company. As a matter of fact, he was the first Licensee for prospecting of iron ore in Champua Sub-Division. The Licence was subsequently granted to M/s Bird & Co. in 1924, who commenced mining around 1927. Most notable contributions in mapping, delineating and estimating the iron ore deposits in the districts of Kendujhar and Sundargarh have been made by H. C. Jones, M. S. Krishnan, B. C. Gupta, J. A. Dunn during the period 1919-1940. Fig. 1 depicts the iron ore deposits in the Singhbhum-Kendujhar-Bonai region. Fig. 2 shows a schematic Geological cross section across the iron ore deposits.

The first systematic exploration of an iron ore deposit was carried out in 1954 by Indian Bureau. of Mines in Barsua, now being worked by Steel Authority of India Limited for supply of ore to Rourkela Steel Plant.

The potentiality of Daitari and Gandhamardan deposits was brought to light by the State Directorate of Mines during 1957-58 and 1962-63 respectively.

Among the latest workers who have made significant contributions for interpretation of geology, structure and genesis of iron ore of Orissa, S. Acharya, A.K. Saha, S.N.Sarkar, K.L. Chakravarty and Tapan Majumdar figure out prominently.

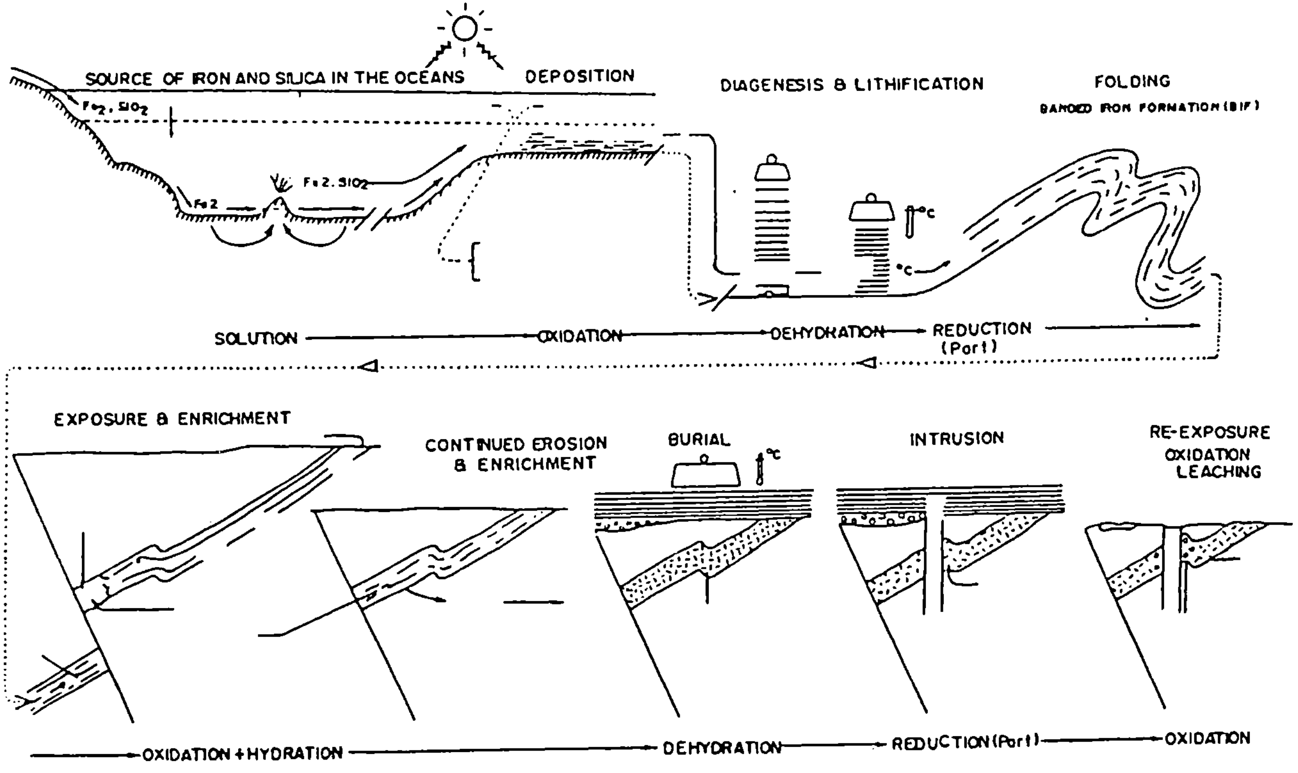
3. GEOLOGY AND ORE TYPES

The iron ore deposits of the State occur in five distinct geographic zones, namely,

a. Bonai-Kendujhar
b. Gandhamardan
c. Tomka-Daitari
d. Gorumahisani - Badampahar
e. Hirapur (in Koraput- now Nowrangpur district)

The parent rocks of the iron ore deposits is Banded Iron Formation (BIF) and more precisely the Banded Hematite Jasper (BHJ) or Banded Hematite Quartzite(BHQ) and Ferruginous shales. The iron bands are also represented by magnetite, martite, goethite, maghemite, although in Orissa, hematite constitutes the predominant band in the layered

FIG. 3 SIMPLIFIED DIAGRAMMATIC MODEL FOR THE GENESIS OF BIF & BIF HOSTED IRON ORES



BIF. The BIF along with volcano-sedimentary rocks pile constitutes what is known as Iron Ore Group or Supergroup. It is believed that these were deposited in ancient ocean basins (ca 3.2 billion years ago) on either side of a central cratonic mass which occupied roughly the present Singhbhum Granite batholith (c.f. Saha et al, 1988). BHJ consists of alternate layers of dark bluish-grey hematite and red coloured jasper, the thickness of bands varying from less that 0.5 cm to 1-1.5 cm. Fig. 3 shows a diagrammatic model for the genesis of BIF and BIF hosted iron ores.

The iron ore bodies are considered to be products of surface alteration of BHJ; the percolating surface and ground water leaching out the silica and fortifying the BHJ with additional iron. Iron content of the unaltered BHJ is around 20-30%, while iron content of the enriched BHJ varies from 55 to 70%. Enrichment of ferruginous shales has also led to formation of iron ore as in some parts of Daitari. But such deposits are rather small in extent. The main iron ore deposits of the State are found along the classic Bonai-Kendujhar horse-shoe shaped iron ore synclinorium in which the tops of ridges contain high grade deposits. The elongated horse shoe shaped synclinorium trends NNE-SSW, open on NNE and is spread over an area of approx 100 km x 30 km. The U shaped configuration of the synclinorium is the result of superposed upright folds with vertical to inclined axial planes on nearly perpendicular axes (E-W & N-S) and the gently plunging nature of the youngest fold (N-S) to the north.

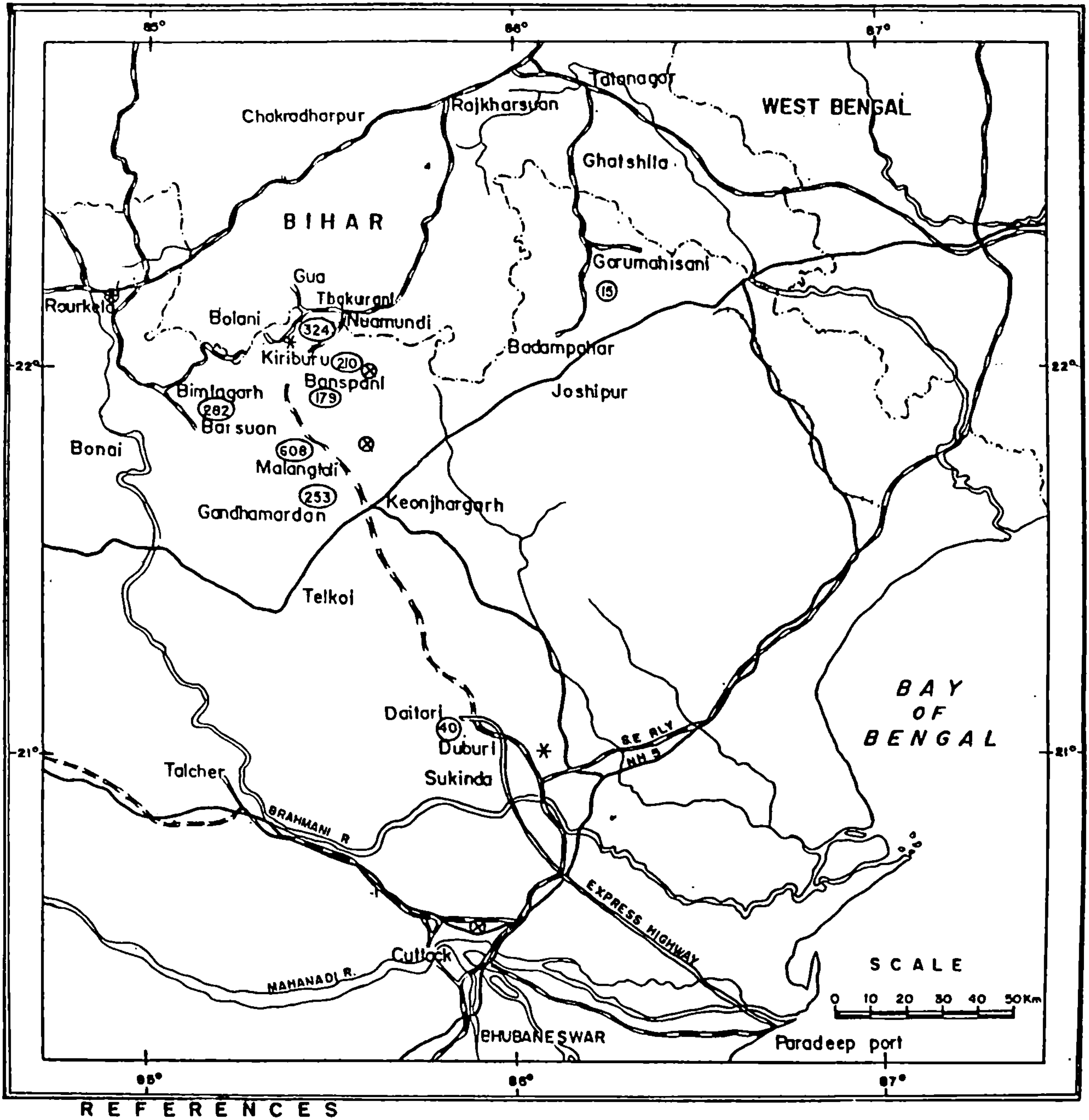
The eastern limb features Thakurani, Joda East, Joribahal, Jilling-Longalata, Jajang and Malangtoli deposits, the last named deposits towards the closure. The western limb features Kiriburu, Bolani, Kalta, Barsua and Khandadhar group of deposits. Gandhamardan and Tomka-Daitari lie in widely separated outcrops towards southeast, the intervening areas occupied by metabasic lavas.

Gorumahisani-Badampahar deposits are associated with banded hematite/ magnetite grunerite and BHJ. It is believed that this litho-assemblage is older to Bonai-Kendujhar BIF.

Hirapur, on the WSW extremity of the State is a small outlier of BIF. It probably is of the same age as that of the BIF of Bailadila complex. Fig. 4 exhibits the principal iron ore deposits of the state.

The broad geological sequence in the four important Iron ore regions of the State are described in order of increasing age.

FIG.4 MAJOR IRON ORE DEPOSITS AND RAILWAY TRANSPORTATION ROUTES



REFERENCES

-·-·- State boundary

▬ ✕ ✕ Railway : Existing/Under construction

—— Roads (N.H, S.H and Expressway)

≈ River

⑩ Iron ore deposit with reserve (in million tonnes)

* ⊛ Iron & Steel Plant : Existing/Under construction

⊗ Sponge Iron Plant

(1) Bonai-Kendujhar

	Alluvium
	Kolhans: Sandstone with shale bands
	Mafic Lavas; Malangtoli Lavas
Iron Ore Group	Upper shales
	BHJ with iron ore
	Lower shales
	Mafic metalavas.

(2) Gandhamardan

	Kolhan sandstone with minor shale and tuff, Malangtoli mafic lavas
	Phyllitic shale & tuff
Iron Ore Group	Ferruginous chert
	BHJ with iron ore.
	(There is indication about occurrence of two horizons of iron ore)

(3) Tomka-Daitari

	Alluvium
	Dolerite Dykes
	Singhbhum Granite
	Quartz-Chlorite-Schist
	BHJ with iron ore,
Iron Ore Group	Ferruginous shales with iron ore, chert, carbonaceous shale, phyllite
	Orthoquartzite
	Meta-lavas
	Conglomerate

(4) Gorumahisani-Badampahar

	Laterite
	Newer Dolerite
	Granite
Iron Ore Group	Shales, Quartzites, Banded Hematite (Magnetite) Grunerite, Quartzites and tuffaceous lava
	Older Dolerites.

Ore types

The ore types which occur in the State include the following;

a.	Massive	(often hard and compact, widely jointed and contain 64-68% Fe)
b.	Laminated	(also biscuity when in fine laminae, medium hard to soft, porous, friable, exhibit folding and crumpling, contain 62-65% Fe)
c.	Shaly	(Shaly textured, brittle contain 61-63% Fe)
d.	Lateritic	(Product of alteration of the former types, porous, contain 56 58% Fe)
e.	Powdery	(Blue Dust) Fine greyish blue, occur in pockets, contain 65-68% Fe.
f.	Recemented ore or canga	Brecciated flat beds with subangular hematite boulders and cobbles embedded in lateritic matrix; overall grade 58-60% Fe

4. EXPLORATION METHODOLOGY

Exploration strategy depends on the nature of information required of a deposit and the extent of reliability of such information. As a matter of fact, exploration strategy has to be tailored to conform to the specifications required by the iron & steel industry both domestic and overseas. Basically, exploration of an iron ore deposit aims at the following objectives;

a. delineation of shape, size and structures of the ore body.

b. determination of physico-chemical and thermal properties.

c. determination of extent of weathering, gangue content and in particular Al_2O_3/SiO_2 ratio, phosphorus, sulphur and alkalies

d. computation of reserve and grade,

e. determination of metallurgical parameters and beneficiation characteristics,

f. determination of lump ore and fine ore recovery, under simulated mining conditions.

g. determination of ore : overburden ratio,

h. determination of environmental parameters.

i. determination of ground water characteristics and rock mechanical property of the ore zone

Exploration strategy is determined accordingly. As the iron ore deposits of Orissa are associated with BIF, bedded type and hematitic, exploration techniques adopted include;

- i. geological mapping (1:25,000, 1:5,000 & 1:2,000 scales) with emphasis on study of stratigraphy, structure and control of ore deposition;
- ii. pitting & trenching,
- iii. drilling (rotary, percussive and rotary-percussive),
- iv. exploratory mining (deep pits and adits),
- v. collection of bulk samples.
- vi. petrological, mineralogical, chemical, mechanical, metallurgical testing,
- vii. computation of reserve and grade by classical and computer methods.

The grid density for pits and bore holes has to be decided on case to case basis. It has been observed that core drilling at 100mx100m grid has provided quite accurate data about the geometry of an iron ore deposit.

The agencies which have carried out systematic exploration for iron ore in Orissa include the Geological Survey of India, Directorate of Mining & Geology, Indian Bureau of Mines, National Mineral Development Corporation, Orissa Mining Corporation, Tata Iron & Steel Company and Steel Authority of India.

5. RESOURCE

Resource is defined as a concentration of naturally occurring material in or on the earths' crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible. On this parlance, the deposits of weathered and structurally disturbed BHQ/ BHJ and ferruginous shales, containing between 30 and 40% iron, which can be beneficiated, would constitute iron ore resource.

Estimation of resource of iron ore in Orissa has so far been confined to hematite and goethite containing minimum 56% iron. It would be therefore appropriate to describe the estimated quantity as Reserve.

Classification of reserve could be based on proportion of lump and fines likely to the recovered from a deposit and end-uses such as blast furnace grade, sponge iron grade. Although iron content in the ore is the main criteria determining its use; constituents like Al_2O_3, SiO_2, P, S, alkalies, LOI are important as also parameters like reducibility, softening start temperature, bulk density, R.D.I. porosity, incidence of blue dust and ultrafine particles.

Out of a total reserve of 10,267 million tonnes of hematitic iron ore estimated in India, Orissa accounts for 2,602 million tonnes (approx 26%).

The following tables indicate district-wise recoverable reserve of hematite in the State, based on inventory prepared by I.B.M as on 1.4.90.

(in million tonnes)

District	**Proved**	**Probable**	**Possible**	**Total**
Cuttack (now Jajpur)	41.00		7.40	48.40
Dhenkanal	-	-	1.12	1.12*
Kendujhar	805.01	231.82	363.17	1,400.00
Koraput (now Nowrangpur)	-	-	2.12	2.12
Mayurbhanj	-	-	11.79	11.79
Sambalpur	-	-	35.00	35.00*
Sundargarh	221.70	284.15	211.68	717.54
Sundargarh Common with Kendujhar	339.94	22.50	23.95	386.39
Total for Orissa	**1,407.65**	**538.47**	**656.24**	**2,602.36**

* The iron ore reserves of Dhenkanal and Sambalpur districts as estimated by I.B.M. are of low grade and not suitable for iron making on economic scale in India at present.

Break-up of grade-wise reserves in Orissa is as follows :

Iron Content (%)	**(in million tonnes)**
+65	82.39
62-65	1,440.56
Below 62	728.80
Blue Dust	8.60
Unclassified	342.01

As mentioned earlier, workable deposits of iron ore in Orissa occur in the districts of Kendujhar, Sundargarh, Mayurbhanj and Cuttack (now Jajpur). The only deposit in Koraput district at Hirapur hill is estimated to contain a reserve of 2.12 million tonnes of 60-62% Fe. Owing to its rather disadvantageous location with respect to consuming centres, the deposit could not be developed so far. The sectoral distribution of important deposits is described in the following table :

District	Deposit	Lessee	Reserve (in million tonnes)	Grade (%Fe)
Kendujhar	Gandhamardan	OMC	253.00	63.45
	Thakurani	Free hold	324.00	64.00
	Joda East	TISCO	210.00	64-66
	Khondbandh	TISCO	54.00	-do-
	Jilling-Longalota	Essel Mining & Industries	87.00	-do-
	Jajang	Rungtas	84.00	-do-
	Joribahal	B.D. Patnaik	8.00	-do-
	Katamati	TISCO	40.00	-do-
	Thakurani-Bhadrasahi Belkundi	BPMEL & OMDC	63.00	63-65
	Bolani	SAIL	324.00	63
	Malangtoli	-	608.00	63 Part lies in Sundargarh dist.
	Seramda-Bhadrasahi	OMC	8.00	63-64
Sundargarh	Barsua	SAIL	139.00	59-62
	Kalta	SAIL	93.00	63
	Khandadhar group	OMC	50.00	61-64
Mayurbhanj	Gorumahisani	G.S. Mishra	4.50	63
	Badampahar	Lal Trades	5.00	60
	Sulaipat	B.C. Dagara	1.50	66
Cuttack	Daitari	OMC	40.00	62 Part lies in Kendujhar dist.

It may be noted that no deposit contains uniform grade of ore. Grade can be improved to +65% Fe. As such, it is possible to produce larger quantity of high grade ore.

6. MINING AND PROCESSING

All iron ore mining operations in the State are opencast and the methods range from manual to mechanised. Most of the mechanised mines have crushing and screening facilities as well.

The hand (manual) mining operations are carried out with the help of picks, shovels, hammers, crowbars and screens (for segregating into different sizes). Compressors and jack hammers are used for drilling blast holes, which are charged with explosives and blasted. The benches are of 3-6m height.

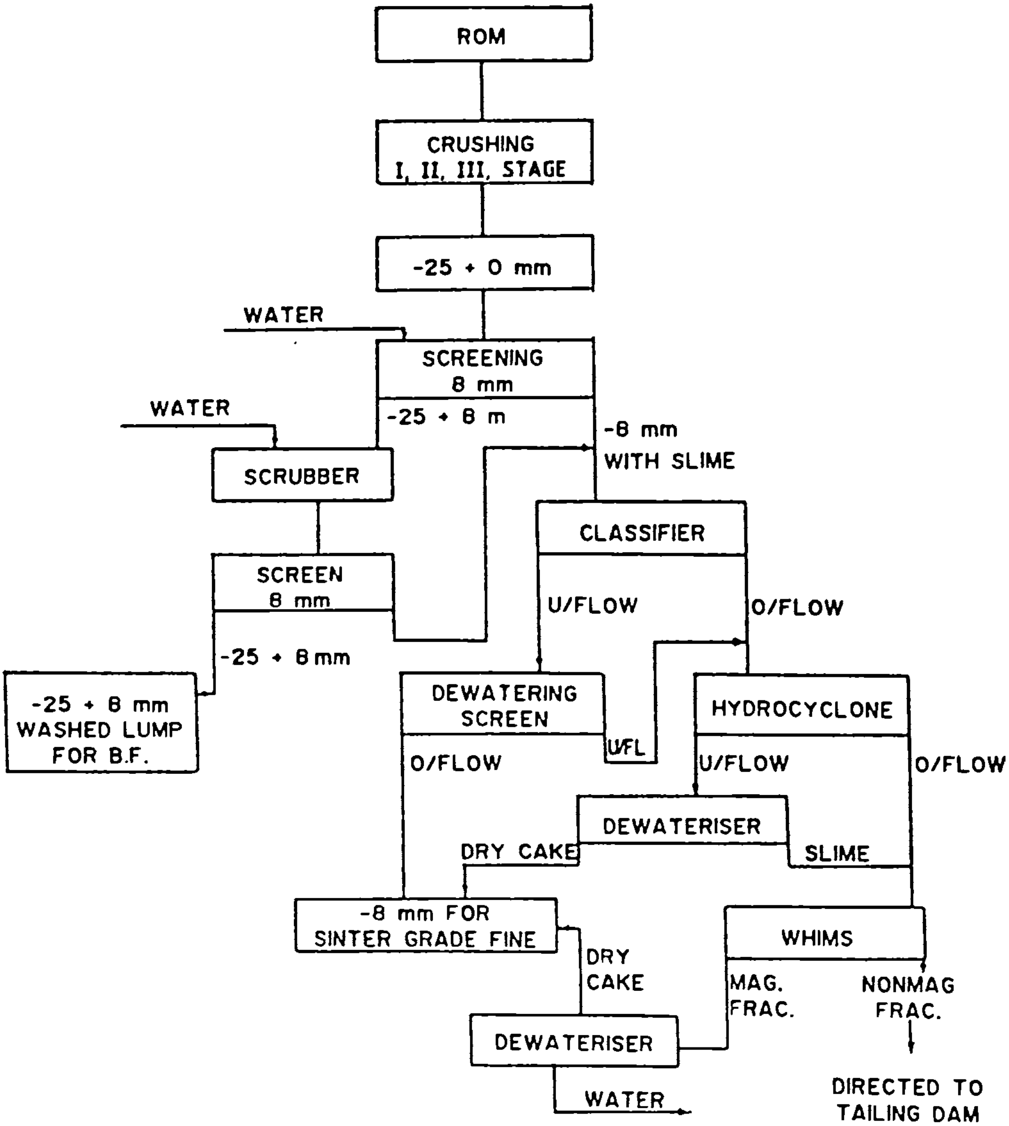


FIG.5 SCHEMATIC FLOW DIAGRAM FOR IRON ORE PROCESSING

The steps involved in machine mining and processing operations are :

a) Drilling,
b) Blasting,
c) Excavation of overburden and ore,
d) Haulage,
e) Crushing and screening.

Mining is carried out by conventional top slicing method, keeping a bench height of 10 to 12 m. Compressed air rotary percussive rigs are used to drill holes ranging from 37 mm to 300 mm dia and blasted with liquid oxygen/special gelatine/slurry/ANFO explosives. The blasted material are loaded (separately as ore and waste) by rope/hydraulic shovels (1.9 to 4.6 m^3 capacity) on to 10-35 tonnes rear dumpers, which transport the ore to the crusher.

Processing of the run of mine ore is imperative to ensure supply of ore of consistent quality and size required by the iron and steel producers. The operations include crushing , grinding, classification, screening, blending and beneficiation (wet scrubbing & jigging, gravity separation and wet high intensity magnetic separation). The objectives of processing iron ore produced in Orissa are two fold, viz, reduction in alumina and increase in iron content. The capacity of the ore processing plants is designed depending on the quantum of output and product sizes.

The products of a beneficiation plant are three, namely, lump, fines and slime. The lump portion can be in different sizes, viz, 6-20 mm, 8-25mm, 10-40mm, 10-50 mm, 10-100 mm depending on the requirements of the integrated steel plants, sponge iron plants and export. The fines for sinter making are in the size ranges-6 mm + 100 mesh, -10 mm + 65 mesh and -10 mm + 100 mesh. Slime constitutes rejects in ultrafine form from which recovery of useful iron values has been planned in Barsua iron ore mines of SAIL through Wet High Intensity Magnetic Separation (WHIMS). A schematic flow diagram for processing of r.o.m ore is exhibited in Fig. 5.

7. USES AND SPECIFICATION

Iron ore is essentially used for production of iron and steel. The other minor uses are as a heavy media (magnetite) in coal washeries and in cement manufacture. Small quantities are used in manufacture of pigments, high density concrete and ferrites. Finely ground hematite are being used in drilling mud as a substitute for barite.

Iron ores produced in Orissa are being utilised for production of iron (including Sponge or Direct Reduced iron) and steel in the integrated iron & steel plants of SAIL at Rourkela. Durgapur, Burnpur and Bokaro (at times); of TISCO at Jamshedpur, sponge iron plants located in different parts of the country and for production of iron in Kalinga Iron Works near Barbil. Some quantity is being exported through Paradip Port.

With the iron and steel makers becoming increasing conscious about the need for improving productivity, the approach is towards obtaining cleaner ore with higher Fe content and least gangue, of homogeneous and consistent quality. The specifications demanded by various end users are as follows;

	% Fe	SiO_2 (max)	Al_2O_3 (max)	P (max)	S (max)	Size
Integrated steel Plants						
Lump	62-65	2	3			8-25 mm/ 10-40 mm
Fines	62	4(SiO_2 + Al_2O_3)				50-75 mm(SMS)
(for sinter)						8
Kalinga Iron Works	63-65	5 (-do-)				10-30
DRI Plants						
Coal based	64 (min)	4.5max (-do-)		0.02	-	6-20
Gas based	67 (min)	3.0 (-do-)		0.04	0.01	6-20
Export						
Lump	63.65	3.5	3.0	0.05	0.02	10-100
Fines (Daitari)	60-62	7 (SiO_2+Al_2O_3)		0.10	0.02	-10mm

8. PRODUCTION

The iron ore mines are confined to the districts of Kendujhar, Sundargarh, Mayurbhanj and Jajpur. The status of leases (as on 1.4.94) is as follows:

		No.	Area (in hectares)
Iron Ore			
	Jajpur	12 (01)	1,813
	Kendujhar	43 (32)	9,943
	Mayurbhanj	10 (08)	3,280
	Sundargarh	19 (11)	4,507
Iron & Manganese Ore			
	Kendujhar	38 (33)	15,977
	Mayurbhanj	1 (01)	185
	Sundargarh	22 (20)	3,283

(Figures within brackets indicate number of leases in operation)

The major producers of iron ore in the State include Orissa Mining Corporation, Steel Authority of India, Tata Iron & Steel Company, Essel Mining & Industries, Rungta Mines, Orissa Mineral Development Company.

Total production in the State during the last 10 years have been as follows :

	('000 tonnes)
1984	6,603
1985	7.101
1986	8,083
1987	8,672
1988	7,726
1989	7,312
1990	8,388
1991	8,702
1992	8,613
1993	7,759

Grade-wise production during 1993 was of the following order :

			(million tonnes)
Lump	65% and above Fe	:	2.662
	62-65% Fe	:	2.460
	60-62% Fe	:	0.079
	Less than 60% Fe	:	0.001
		Total	**5.202**
Fines	65% Fe and above	:	0.081
	62-65% Fe	:	1.931
	62-65% Fe	:	0.538
	Less than 60% Fe	:	0.007
		Total	**2.557**

About 70% of the total production of iron ore in the State is being contributed by only 7 mines out of about 86 producing mines. The State presently accounts for about 16% of the total production of the country (57 million tonnes).

9. DESCRIPTION OF DEPOSITS

The status of development of a few important deposits of iron ore of the State is described in the following paragraphs.

Daitari

The iron ore deposit at Daitari forms the eastermost outlier of the BIF of Kendujhar - Bonai. Lying on the border of Kendujhar and Cuttack (now Jajpur) district at an elevation of 850m, the ore body extends for a strike length of 1,400 metres. The deposit was investigated by the Directorate of Mines and I.B.M. during the period 1958-62 and a reserve of 50 million tonnes having an average iron content of 61.50% was proved upto a depth of 110 metres. This led to the development of a port at Paradip with mechanised ore handling facility and an expressway linking Paradip Port with Daitari for transportation of Iron ore over a distance of 154 kms. for export.

A mechanised mine including ore processing plant was commissioned by OMC in 1974 for production of annually 1.2 million tonnes of washed lump and fines. This has remained grossly under-utilised owing to lack of export market. The annual production has ranged between 2 and 3 lakh tonnes.

The ore of Daitari is hematite and laminated. Occurrence of blue dust has been recorded. Lump recovery is estimated to be around 40% while slime loss varies between 8 and 12% of the r.o.m. feed.

Mining operations consist of conventional drilling and blasting, shovel-dumper combination working in 10 m high benches. The r.o.m. ore is subjected to primary and secondary crushing and washing and the products are transported by a 3.8 km. long down the hill belt conveyor on to the lump ore loading bin and fines stockpile. The lump ore ranges in size from 10mm to 100 mm and the fines from - 10mm to +65 mesh.

OMC holds a mining lease over 1812 hectares and about 40 million tonnes of ore are presently available for extraction. Anticipating demand by the new iron and steel plants proposed to be set up in the vicinity of Daitari, OMC has proposed to revamp the mine for a r.o.m. production of 1 million tonnes per annum. The products will have the following composition;

	%Fe	SiO_2	Al_2O_3	LOI	P	S	Quantity (in tonnes)
R.O.M. feed	62.00	1.82	2.80	6.00	0.08	0.005	
Products							
Sized ore	63.00	1.40	2.20	6.00	0.08	0.005	3,40,000
Ore fines	62.50	1.50	2.70	6.00	0.08	0.005	4,85,000

Gandhamardan

An outlier of Bonai-Kendujhar BIF, Gandhamardan deposit is associated with BHJ. The main (Peak) ore body extends for a strike length of 3.6 kms. in a N-S direction, the average width is 650 metres On the basis of detailed investigation carried out by OMC, total reserve of 253 million tonnes has been computed with 63.45% Fe, 2.39% SiO_2, 2.32% Al_2O_3 and 3.10% LOI, Phos. & S contents are low, being of the order of 0.05% and 0.01% respectively. The ore mineral is hematite and the type - laminated.

The deposit is located at a distance of 16 kms from Kendujhargarh and rises 400-450 metres from the surrounding plains, to an elevation of 1,062 metres at the peak. The deposit at its base will be connected with Goaldih R.S. on the proposed Banspani-Daitari rail line, the distance being 6 kms.

OMC has proposed to develop a mechanised mine with ore processing plant for an annual output of 4 million tonnes of r.o.m. ore. The products envisaged will be as follows :

Product	Quantity (Tonnes)	Weight%	Moisture%	%Fe	%SiO_2	%Al_2O_3
Lump						
-50+20mm	741,000	19	5	65.30	1.68	2.80
-20+6mm	858,000	22	5	65.50	1.65	2.75
Fines						
-6mm+100 mesh	2,085,780	52	10	65.40	1.72	3.00
Slimes		7		42.20	14.00	14.50

Mining lease of the main deposit is held by Orissa Mining Corporation. At present, mining operations are being carried out on a limited scale, annual production being of the order of 1,00,000 tonnes.

Malangtoli

Malangtoli block in Kendujhar district comprises a group of 13 deposits spread over an area of about 20 sq.kms. The deposits occupy the eastern part of the southern closed end of the NNE plunging synclinorium and are associated with BHJ. The deposits have been investigated in detail by GSI. and NMDC and a total reserve of 608 million tonnes of average 63% Fe has been proved. The ore types include massive, hard and soft laminated, powdery and lateritic with some localised canga patches. The base of the main deposit (Pipokri) is at a distance of 16 kms from Banspani R.S. The deposit is yet to be worked. Development of the deposits for an annual output of 5-7 million tonnes is being planned.

Barsua

Barsua along with Taldih and Kalta blocks constitute principal sources of iron ore for Rourkela Steel Plant. A mechanised mine with ore processing and beneficiation facilities have been established at Barsua for an annual production of 2 million tonnes.

The ore body associated with BHJ/BHQ and ferruginous shales occurs as a cap of variable width and thickness, strikes in a NE-SW direction, complexely folded, lateritised at the surface and irregularly enriched. Thickness ranges upto 100 metres, average being 48.8 metres. The ore types include massive, laminated (hard and soft), lateritic and blue dust. Mineralogically, ore is predominantly hematite with goethite association. The deposit has been explored in detail initially by I.B.M. and then by Rourkela Steel Plant authorities by boreholes spaced at 100 m apart. A total minable reserve of 139 million tonnes has been estimated with an average iron content of 61%.

The mine is being worked by conventional top slicing method, keeping a bench height of 10m and max. pit slope of 45°. The ore is drilled by 150 mm DTH drills and blasted with LOX, ammon. nitrate and other conventional explosives. The fragmented ore is loaded by power shovels (3.1 m^3/4.6 m^3) on to 35 t rear dumper for haulage to crusher, the roads having a gradient of 1 in 16. The ore is crushed in two stages to -50 mm size, dry screened into -50+10 m lump and -10 mm fines. In the wet circuit, the crushed ore is subjected to washing and jigging.

About 19% of the r.o.m. feed is lost in the form of slime. The average upgradation in Fe content for lump is 1.5% and 5% in case of fines : The products analyse as follows :

	%Fe	SiO_2	Al_2O_3
Lump (10-50 mm)	61±1	2.5±0.5	4.0±1.0
Fines (-10 mm)	60±1	3.0±0.5	4.5±1.0

The current production is 1.5 million tonnes and after modernisation, total output will be 2 million tonnes comprising 0.63 million tonnes of lump and 1.37 million tonnes fines. It is proposed to produce 0.3 million tonnes of concentrates per annum assaying 64-65% Fe from slimes containing 48-60% Fe by WHIMS when the output will be increased to 2.2 mtpa (0.6 mt. lump & 1.6 mt. fines).

10. EXPORT

Iron ore produced in the erstwhile princely State of Mayurbhanj and Kendujhar were being exported in small quantities through Calcutta port during 1945-50 and 1950s. Regular large scale export commenced with the commissioning of mechanical ore handling facilities at Paradip during 1966. Export comprised both lump (10-100mm) and fines (-10 mm) and the grades ranged between 62 and 65% Fe. The main sources have been Daitari and Gandhamardan mines of Orissa Mining Corporation and mines in Banspani-Barbil-Barajamda sector. In the absence of a direct rail link between Banspani - Barbil and Paradip, ore procured from the mines in Banspani-Barbil-Barajamda region are being hauled by rail to Paradip over a circuitous route via Kharagpur.

Export of iron ore during the last 10 years have been of the following order:

	Quantity (in '000 tonnes)
1983	1,175
1984	1,296
1985	1,868
1986	1,852
1987	2,143
1988	1,542
1989	1,765
1990	1,935
1991	1,737
1992	1,173
1993	1,410

Countries to which exports have been made include Japan, South Korea, North Korea, Romania, Hungary, Pakistan, China, Italy, Czechoslovakia, Turkey, Australia.

Export prospect will improve substantially once facilities are provided at Paradip port to load vessels of 1,50,000 DWT and above and Banspani is connected with Daitari by a direct rail link. Entire export of iron ore from Orissa is canalised through the Minerals & Metals Trading Corporation of India Limited (MMTC).

11. ENVIRONMENTAL CONSIDERATIONS

Iron ore mining and processing have profound influence on all elements of environment, viz. land, water, air, vegetation and habitat. The activities which contribute to the disturbance and degradation of the environment include drilling, blasting, stripping of top soil and vegetative cover (forest growth) excavation of overburden and ore, loading and haulage; crushing and screening, washing, disposal of solid waste and slime. The adverse impacts are more pronounced in the mechanised mines as in Daitari, Barsua, Bolani and Joda east.

Legislative measures in the form of Forest (Conservation) Act, 1980, Environment (Protection) Act, 1986, Mines & Minerals (Regulation & Development) Act as amended provide ample safeguards against degradation of forest, land, water and air quality on account of mining activity. As a result, new mining activities are allowed on the approval of environment management plans, mining plans and compensatory afforestation (in case of diversion of forest lands) and adherence to environmental norms set out in the aforesaid legislations. Existing mining activities are also required to conform to the prescribed environmental norms.

Out of about 1,200 sq. kms. of land area occupied by mining leases in the State, iron ore accounts for 227 sq. kms. and combinedly with manganese ore another 192 sq.kms. The area under actual mining operations is estimated to be less than 100 sq. kms. and iron ore mining activities during the next 10 years are expected to be confined to this area. Environmental impact assessment studies have been carried out in Daitari, Gandhamardan, Joda east, Bolani and a number of mines, Environmental Management Plans and control measures have been drawn up. The control measures include -

a. preservation of top soil,

b. reclamation/stabilisation of quarried out areas through biological methods.

c. plantation and afforestation, provision of green belt,

d. regular sprinkling of water on haul roads,

e. provision of earthen dams/tailing pond with tailing dam for arresting wash off/impounding the slimes,

f. creation of "species bank" based on local varieties of flora,

g. storage of silt, diesel wash, grease etc. in pits to prevent their flow to surface water and treatment thereof for future use,

h. provision of dust trap,

i. provision of ear muffs,

j. muffled blasting.

12. OUTLOOK

The State now produces around 8 million tonnes of iron ore annually providing direct employment to about 14,300 workers. The value of production is estimated to be Rs.1183 million. The State earns a revenue of Rs. 90 million by way of royalty on iron ore.

Work on the establishment of a 0.5 million tonne/year pig iron plant by Mid East Steel Company Limited (MESCO) near Jajpur Road is fast nearing completion. This is likely to be expanded to 1.2 mtpa. Additional iron making facilities with a total annual output of 6 million tonnes of steel are planned in the area. With liberalisation of economy and announcement of the new National Mineral Policy, reputed companies from abroad have shown interest for develolpment of iron ore mines in Orissa.

These developments together with completion of the modernisation of the integrated steel plants of SAIL at Rourkela, Durgapur and Burnpur and of TISCO at Jamshedpur will lead to step up in production of iron ore to around 20 million tonnes/year by 2000 AD. Export of iron ore will continue, Materialisation of the projects will call for appropriate developments in rail and road communication, generation of power and port facilities.

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Limestone and Dolomite

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1. INTRODUCTION

Limestone is a calcareous sedimentary rock composed of mineral calcite ($CaCO_3$) which on calcination yields lime (CaO) for a wide range of industrial uses. In its purest form, limestone should contain 56% CaO and 44% CO_2. However, it seldom occurs as such in nature. The constituents usually associated include silica, alumina, magnesia, iron oxide, alkalies, water of crystallization and these along with certain physical properties like decrepitation determine the usage of limestone. Other elemental constituents are phosphorous, manganese and sulphur.

Dolomite is a double carbonate of calcium and magnesium containing 30.4% CaO, 21.7% MgO and 47.9% CO_2 in its purest form. But like limestone, it contains silica, alumina, iron oxides, alkalies, P, S etc.

Limestone and Dolomite occurrences are widespread and the resources are vast. In India, limestone occurs in all the States, but low silica limestone occurrences are confined to the sub-Himalayan region in the States of U.P., Himachal Pradesh, Meghalaya, J & K, Nagaland and far away Jaisalmer in Rajasthan where mining is subject to environmental restrictions. Major deposits of dolomite are found in the States of M.P., W.B., Karnataka, Gujarat, Arunachal Pradesh, A.P., Maharastra, Rajasthan and Orissa.

2. GEOLOGY

Orissa is endowed with vast resources of limestone occurring in three distinct geological settings, namely, Gangpur Group, Vindhyan and the Eastern Ghats. Dolomite is mostly confined to Gangpur and Vindhyan Groups.

2.1 Gangpur Group

It is an important stratigraphic unit in Orissa and has been studied by several workers, notably Krishnan (1937), Kanungo and Mahalik (1967 & 1975) and others. It forms a synclinorium structure with inverted limbs (Kanungo & Mahalik, 1967). The Biramitrapur formation hosts important horizons of limestone and dolomite, which extend over lengths of 50 km and

96 km in the northern and southern limbs of the synclinorium respectively. The average thickness of the formation is about 700 m. The major deposits are located at Biramitrapur, Hatibari, Purunapani in the northern limb; Lanjiberna, Gomardih, Khatkurbahal, Kutra in the southern limb and Dublabera in the core of the synclinorium, all in Sundargarh district.

2.2 Vindhyan Group

Vindhyan sedimentaries occur over a vast stretch in western and southern parts of the State, along the Orissa - M.P. border. They are found in four detached basins, namely (1) Chhatisgarh, (2) Nawapara, (3) Indravati and (4) Sukma. The important calcareous members of workable dimensions in the Proterozoic basins are located near Dungri (Chhatisgarh basin, Bargad district), Kotpad (Indravati basin, Nowrangpur district) and Kottameta - Nandivada (Sukma basin, Malkangiri district).

Extensive stretches of limestone are exposed around Dungri for a length of 16 kms.

The limestone and dolomite deposits of Indravati basin are seen along Kolab river near Kotpad along Orissa - M.P. border. Down south in Malkangiri district in Sukma Proterozoic basin, limestone horizon extending for about 7.5 km and widths varying from 0.5 to 2.5 km is exposed between Kottameta in the east upto Sabari river in the west. This rock group comprises quartzite, phyllite and shales.

2.3 Eastern Ghats Group

Limestone associated with calc-granulite, khondalite, quartzite of the Eastern Ghat Supergroup occur in Sunki valley of Koraput, around Khariar in Nawapara and adjoining parts of Bolangir district. The limestone is hard, compact, coarsely crystalline and can be termed as a carbonatite.

3. EXPLORATION AND RESERVE

Over the years, the limestone and dolomite occurrences of the State have been extensively explored and their reserves assessed by systematic diamond core drilling by the Directorate of Mining & Geology (DMG). Other agencies and organisations who have undertaken proving operations in their respective leaseholds include the Orissa Mining Corporation (OMC), Tata Iron & Steel Company (TISCO), Rourkela Steel Plant (RSP), Industrial Development Corporation of Orissa (IDCOL), Orissa Cement Limited (OCL) and Bisra Stone & Lime Company (BSL Co.)

The all India recoverable reserves of limestone and dolomite as on 1.4.90 are estimated at respectively 76,446 million tonnes and 4,967 million tonnes (Source : Indian Minerals Yearbook, 1993). Cement grade limestone accounts for 68% of the total reserve. BF, SMS (OH & LD) and chemical grades amount to 5,544 million tonnes, 4,710 million tonnes and 2,685 million tonnes respectively. As regards dolomite , BF and sintering grades account for about 40% of the total reserve.

4. DESCRIPTION OF MAJOR DEPOSITS

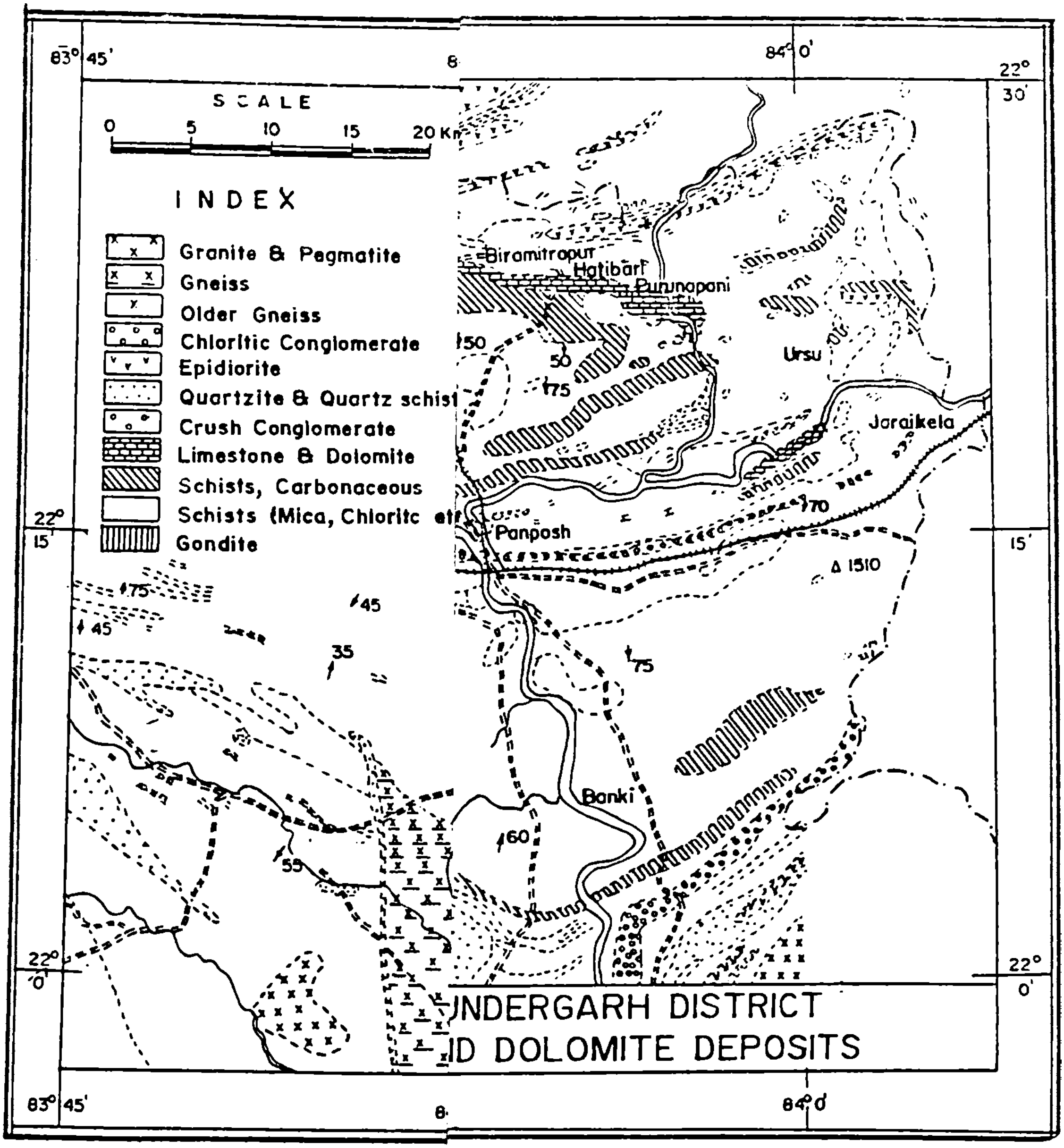
4.1 Sundargarh District

Biramitrapur

The limestone and dolomite bands associated with phyllite extend over a strike length of about 7 km in an E-W direction with a dip of 60°-70° due north. The width ranges from 300 m to 400m and depth upto which occurrence of limestone and dolomite has been indicated is 90 metres. Bisra Stone & Lime Company holds a lease over 1099 hectares comprising six blocks. Of these, only one block (Block XI) is under exploitation, where 2 limestone and 4 dolomite quarries have been developed, the depths ranging from 8 m to 46 m. The reserves estimated along with grades for different blocks are as follows.

Block XI

Estimated	Low alkali limestone :	9.7	million	tonnes	(proved)
upto a depth	Low silica limestone :	4.9	"	"	(")
of 84 metres	Cement grade limestone :	19.5	"	"	(")
	BF grade limestone :	14.4	"	"	(")
		320.0	(Probable + Possible)		
Low silica	dolomite	7.4	"		(proved)
B.F. grade	dolomite				
	(< 4% SiO_2)	42.8	"	"	(")
	(< 7% SiO_2)	56.3	"	"	(")
	(< 7% SiO_2)	188.0	(probable+ possible)		



UNDERGARH DISTRICT
ID DOLOMITE DEPOSITS

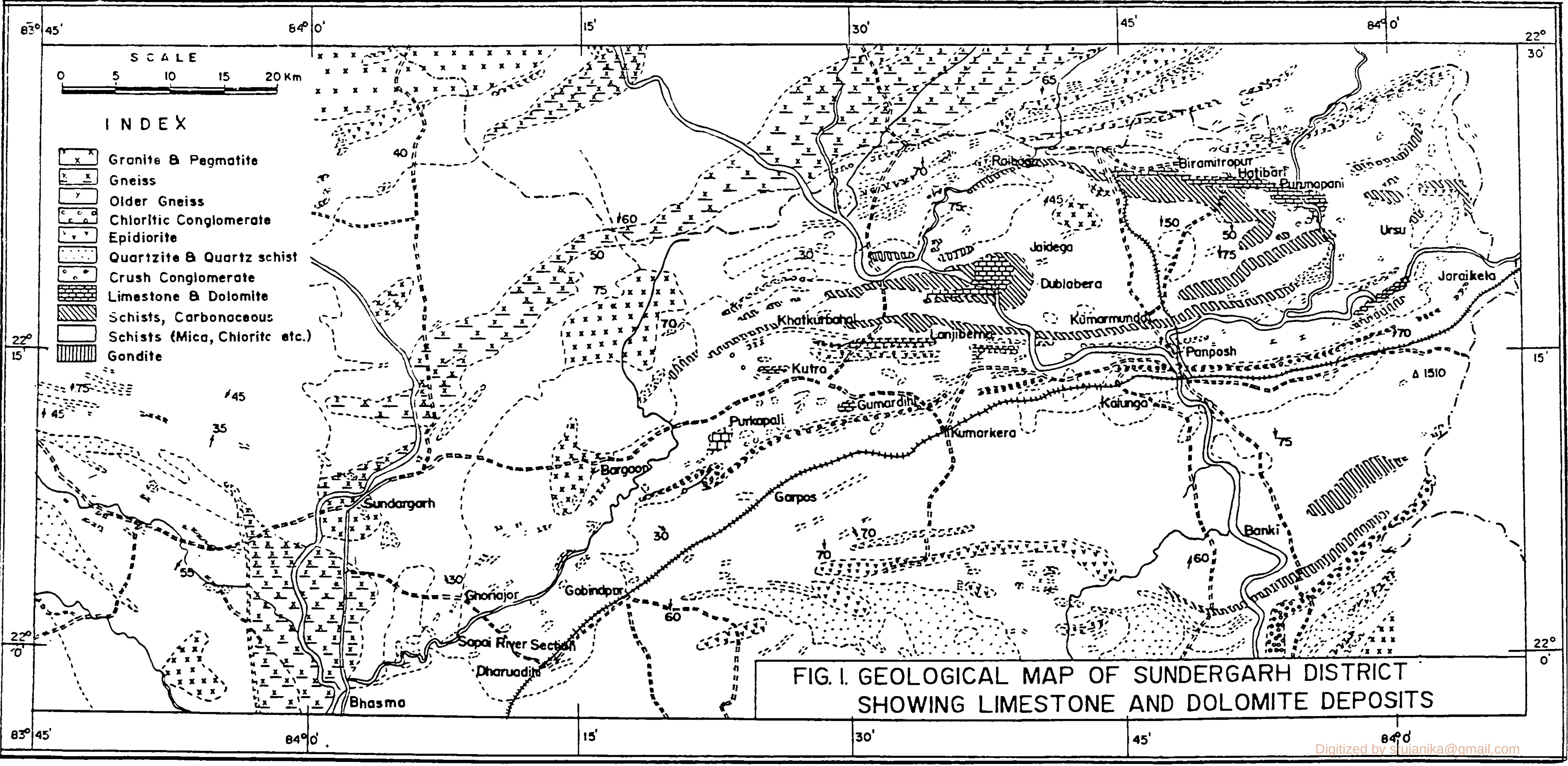


FIG. I. GEOLOGICAL MAP OF SUNDERGARH DISTRICT SHOWING LIMESTONE AND DOLOMITE DEPOSITS

The entire production (0.85 million tonnes / year) is utilised for production of cement at the Cement Works of Orissa Cement Limited at Rajgangpur.

Hatibari-Purnapani-Gatitangar

The belt essentially consisting of limestone extends for about 5.5 kms. in an almost E-W direction, the dip varying from 60° southerly to nearly vertical. Hatibari deposit under lease to TISCO has been abandoned after several years of working on account of high alkali content (.> 0.3%)

The other important mine in this sector is at Purnapani of Rourkela Steel Plant. Limestone occurs interbanded with quartzite, mica schist and phyllite. The geological reserve estimated was of the order of 62 million tonnes with average 9% acid insolubles (AI). The mineable reserve is estimated at 29 million tonnes with AI averaging 8.6% and limestone to waste ratio of 1: 0.63. The average MgO content varies from 3 to 5%, and total alkali (K_2O + Na_2O) ranges from 0.3 to 0.7%. CaO, on an average is 46%.

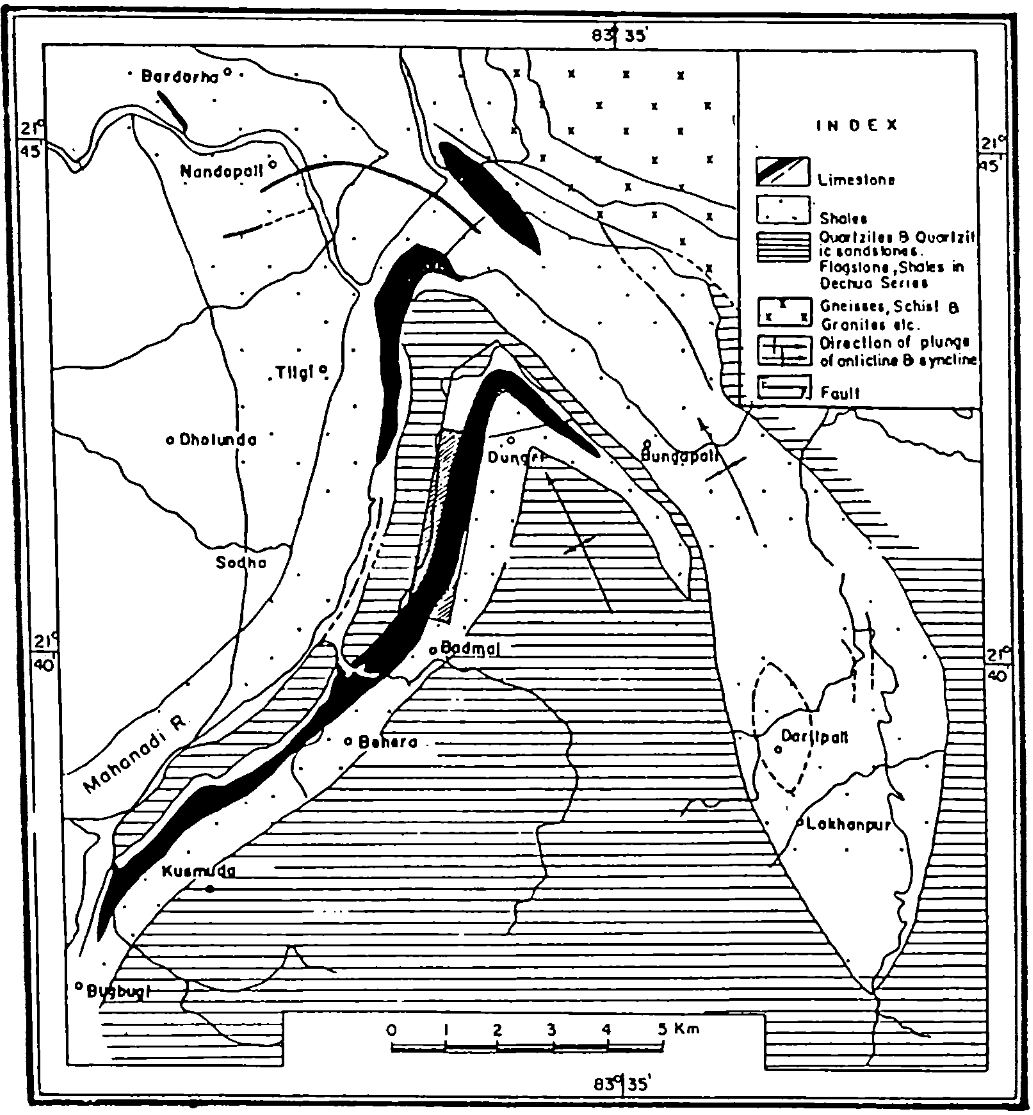
Quarrying is being carried out by both mechanised and manual methods. The mechanised section is having 6m high benches. Mining method is by the conventional DTH drilling, blasting and shovel-dumper combination. Limestone quarried from the mechanical section is crushed and screened to three sized products, viz, 50 - 80m, 25 - 50 mm and 6 - 25 mm and supplied mainly to RSP for use in the blast furnace.

Gomardihi

Dolomites associated with limestone, calcareous shale, phyllite and mica schist occur in the area. The general strike of the bands is almost E-W, dip is 60° southerly. Dolomite is being quarried by TISCO Ltd. under a lease and the mining method is semi - mechanised. One quarry measuring 330 m x 280 m x 30 m has been developed, with one bench of 5 m height in overburden and 7 benches in dolomite each of 4m height. Reserves proved upto a depth of 35 m are placed at 9 million tonnes. As continuation of dolomite has been proved upto a depth of 50m and beyond, the total reserves in the property are estimated at 30 million tonnes. The average grade of dolomite being mined by TISCO is as follows

CaO	28.33%
MgO	20.48%
SiO_2	4.36%
Al_2O_3	1.10%
Fe_2O_3	0.78%
LOI	44.60%
Total alkali	0 25%

FIG.2 REGIONAL GEOLOGICAL PLAN OF DUNGRI LIMESTONE BELT



Dolomite as mined is crushed and screened to yield products in the size ranges of -75 +25 mm (lumps), - 25 + 6 mm (chips), - 10 + 6mm (special chips), -40 + 25 mm (dolo flux), -8 + 3mm (pen size) and - 6 mm (dolo fines). Bulk (about 80%) of the production during 1993-94 were in -75 + 25 mm and -25 + 6 m size ranges.

Fig. 1 shows the limestone and dolomite deposits of Sundargarh district.

4.2 Dungri- Banjipali-Jampali (Bargad district)

Limestone in this belt extends for a total length of 16 km and disposed in the form of an asymmetrical anticline plunging NW. The longer limb (13 km) strikes NNE - SSW to NE-SW and dips 7°-10° westwards. The limestone is both underlain and overlain by quartzite and shales. The width varies from 50 to 250 m. Detailed investigation comprising systematic core drilling has been carried out by the Directorate of Mining & Geology, Orissa. Mining Corporation and the Industrial Development Corporation of Orissa (IDCOL). Associated Cement Company (ACC) also carried out drilling on behalf of IDCOL. Besides, Holtech and Development Consultants Private Ltd. (DCPL) have been associated in computation of reserve and grade, based on drilling data. IDCOL held mining leases over two blocks, viz., Dungri (502 hectares) and Behera-Banjipali (302 hectares). The leases are now held by IDCOL Cement Limited, a subsidiary of IDCOL. Reserves of cement grade limestone estimated are as follows

Dungri (currently under mining)	24	million	tonnes.*
Banjipali	3	"	"
Jampali	29	"	"

(* Reserve available for extraction as on 1.4.94)

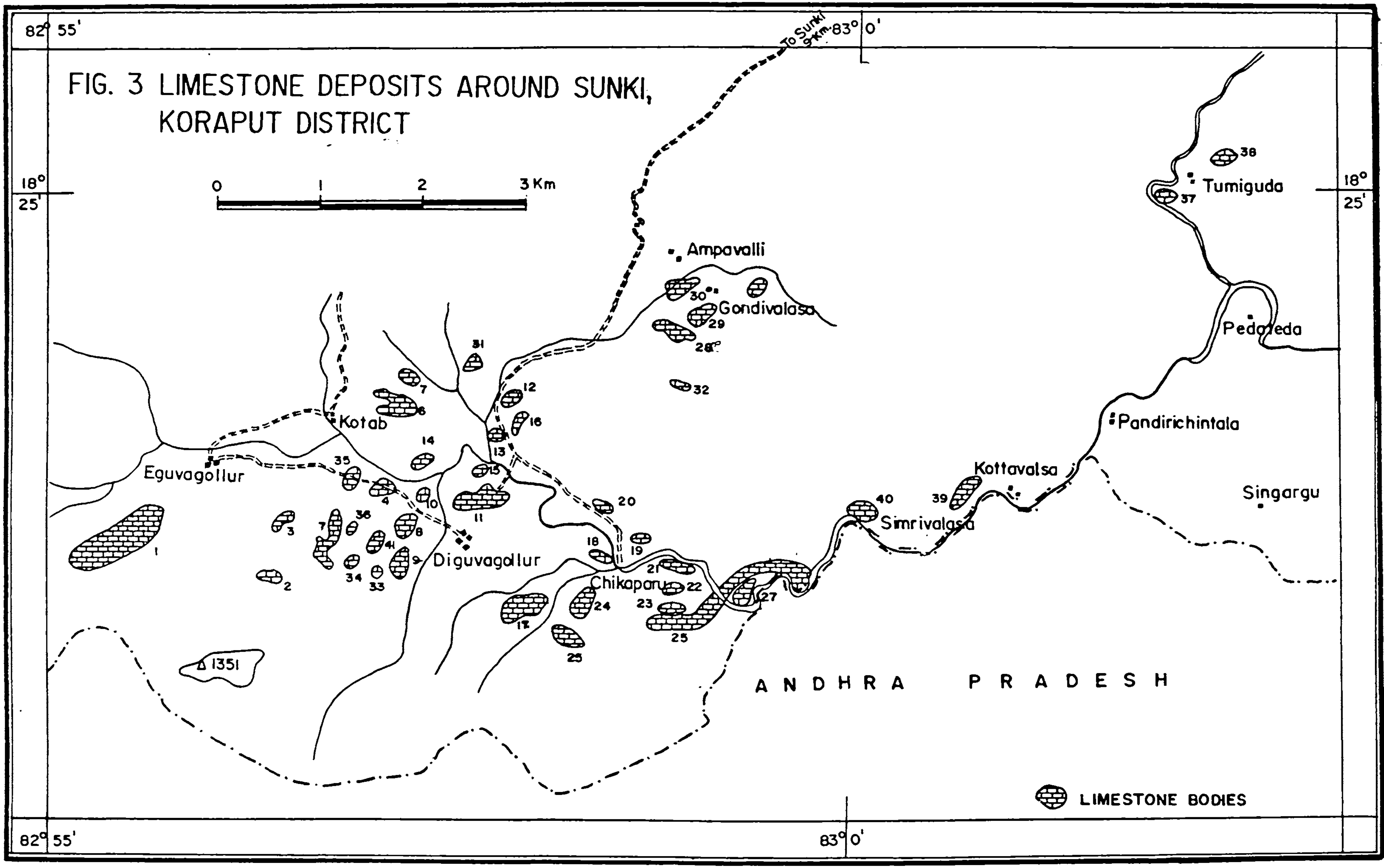
The reserves in these blocks have been computed at overburden to limestone ratio of 2.6 : 1.

Analysis results of a few representative samples are as follows

CaO : 45 - 48%, SiO_2 : 8 - 12%, Al_2O_3 1.5 - 02%,
MgO : 0.9 - 1.2%, Fe_2O_3: 0.6 - 1.0%, LOI 36 - 38%,
P_2O_5 : 0.1%, SO_3 : 0.1%

The total alkali content is less than 0.3%. Limestone of this belt with a total carbonate content of more than 78% is considered suitable for manufacture of cement. Of particular significance is the low magnesia content.

FIG. 3 LIMESTONE DEPOSITS AROUND SUNKI, KORAPUT DISTRICT



Limestone quarried from Dungri is transported over a 48 km long MG railway line to the cement works of IDCOL Cement Limited near Bargad. Mining is manual to semi-mechanised. The 1,200 tpd cement plant is being modernised and expanded for an additional production of 1,800 tpd slag cement. At full capacity, the annual requirement of limestone will be about 1.5 million tonnes, to be met from Dungri-Banjipali-Jampali sector to the extent of at least 90%.

Fig. 2 shows the disposition of limestone in this belt.

4.3 Umpavalli - Tummiguda (Sunki Valley), Koraput district

The deposits occur as lensoid bodies in a geological setting of Eastern Ghats Supergroup dominated by calc-granulites in an area of about 40 sq. kms (Fig. 3). The limestone is crystalline, white, medium to coarse grained. The regional trend of foliation is N 70° E - S 70° W, dip is southerly at angles varying from 45° to 50°. Minor associations of graphite, pyrite, apatite and rare earth elements are observed. A total number of 42 occurrences of varying dimensions have been delineated. Systematic core drilling has been carried out by the DMG to prove the reserves. Orissa Mining Corporation has also carried out drilling in their leasehold. The reserves proved and grades determined are as follows :

Deposit	**Reserves (in million tonnes)**	**%CaO**	**% MgO**	**% Total Insolubles**
Gondivalsa	43	50-51	1-2	6-8
Kotavalsa	3.5	50-51	1	2-4
Pedapadu	0.5	49	1-2	7
Chikaparu	7.3	45-46	2-3.2	8-12
Diguvagulur	9.0	47-51	0.8-2.3	7-12

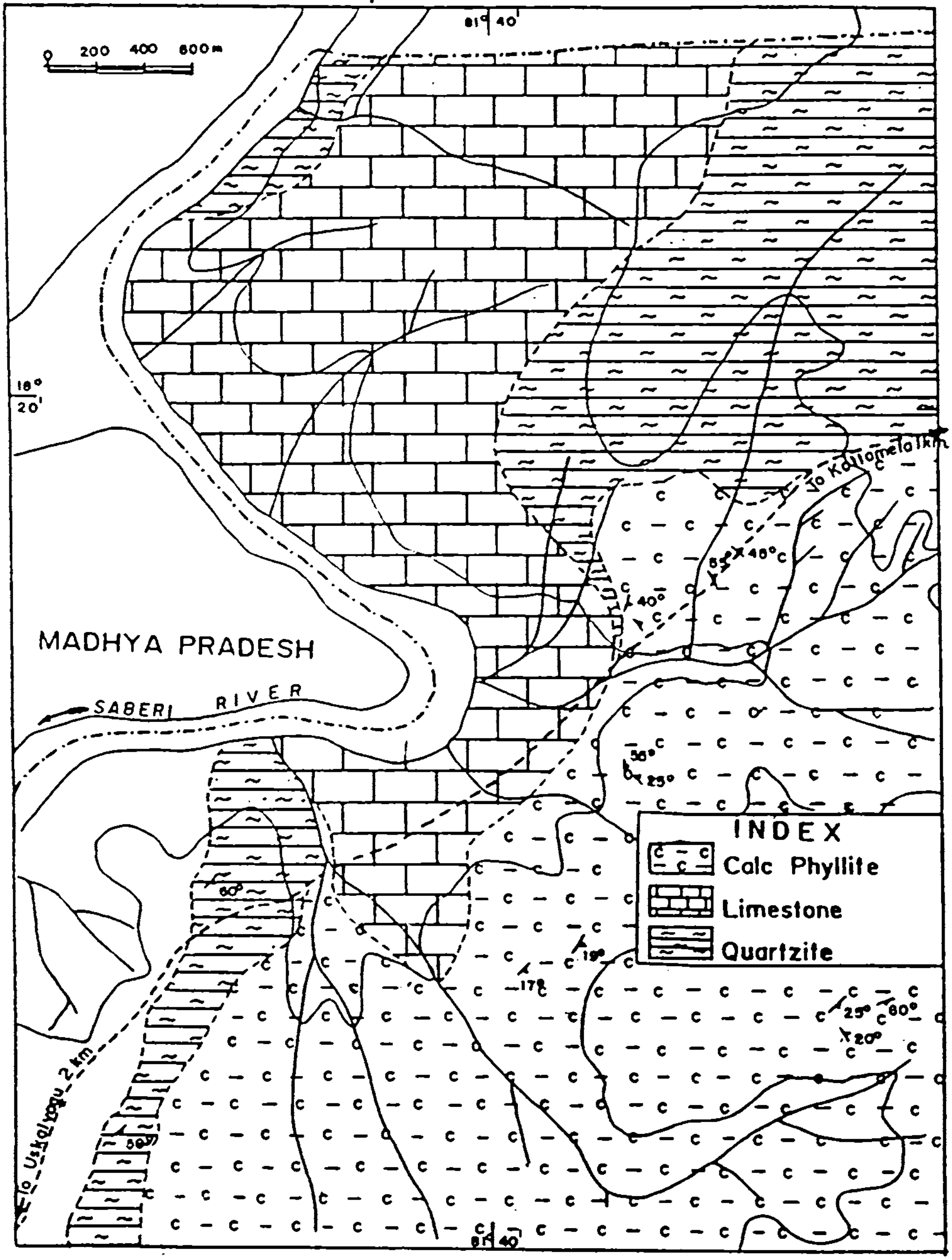
Total alkali content is less than 0.1%

Manual quarrying is being done by OMC, and IDCOL for meeting the requirements of the cement plant in Sunki valley and a few mini-cement plants.

4.4 Kottameta-Nandiveda-Uskalvagu (Malkangiri district)

Limestone occurs interbanded with shale, phyllite and quartzite, over a strike length of 5 km with an average width of 30 m and thickness of over 80 m. This constitutes the largest unexploited limestone reserve

FIG.4 LIMESTONE DEPOSITS OF KOTTAMETA-NANDIVEDA-USKALVAGU BELT, MALKANGIRI DISTRICT



of the State. The formations strike N-S and the dip is 5° - 25° easterly. The deposits have been investigated in detail by systematic core drilling. The total reserves estimated are 240 million tonnes of BF & cement grade limestone. CaO content ranges from 45 to 50%, SiO_2 upto 14% and MgO is usually low being less than 2%. Alkali content is also low (less than 0.2%).

The limestone deposits of this belt are shown in Fig. 4.

Following is a summarised statement of reserves and grade of major deposits.

	Reserves (million tonnes)	Grade (%)		
(1) Sundargarh district		**CaO**	**MgO**	**TI**
a. Biramitrapur-Raiboga	400 (Limestone)	46.5	3.5	6-10
	324 (Dolomite)	29.0	20.0	5-9
b. Hatibari-Purnapani-Gatitangar Purnapani	29 (Limestone)	46	3-5	10
c. Lanjiberna	42 (Limestone)	45-50	1.5-3.4	6-12
d. Gomardih	30 (Dolomite)	28.3	20.5	6
e. Khatkurbahal-Kiringsera-Kandeimunda-Litibera-Kutra-Teleghana	20 (limestone)	45.5	2.5	8-12
	22 (Dolomite)			
f. Sapai river section	5.4 (Dolomite)			
g. Lifripara	1.7 (Dolomite)			
h. Dublabera	3 (Dolomite)			

The alkali content of most of the limestone and dolomite deposits in Biramitrapur belt is high, being more than 0.30%. Higher alkali adversely affects the linings of the furnace and consequently the productivity.

	Reserves (million tonnes)	CaO	MgO	TI
(2). Umpavalli-Tummiguda-Gondivalsa deposits Sunki valley, Koraput district	63.0	45.5-51	0.5-3	2-12
		(mostly cement, partly chemical grade)		
(3). Kottameta-Nandivada-Dharampalli-Uskalvagu deposits, Malkangiri district	240	46-50	<2	6-14
		(Mostly cement & BF grades)		

	Reserves (million tonnes)	Grade (%)		
		CaO	MgO	TI
(4). Dumajodi-Binsuli-Parsaguda deposits, Nowrangpur district	14	Dolomitic Limestone (only selected patches are suitable for use as dolomite)		
(5). Nuapada district .				
a. Chandapala	2.2	47.8	0.5	6-12
b. Deobahal	2.0	48	2.0	6-12
c. Rohanpadar	3.3	48	1.8-3.5	6-10
d. Sagundungri	1.5	48.5	1.0	8-10
e. Ghasipara, Chalanpara, San Maheswar, Khariar deposits	Not estimated			
f. Bedded deposits of Purana group of Chhatisgarh basin (Jogbhata, Kundanjhariya, Gendulpani, Kharupani, Porapadar, Jholapara, Sindursil)		All these occurrences are of low CaO, high silica and magnesia content. Selective patches are utilisable		
(6). Bargad district				
i) Dungri - Banjipali-Jampali,	56	45-48.8	0.9-1.2	10-13
ii) Putka-Saramsil,	2.0 (Limestone)			
22.0 (Dolomite)	28	19-20	7-9	
(7). Dhamandanga Kuliadara, Karlabhali & Hial (Several discontinuous deposits) Bolangir district	2.0	42-53	<2	1.5-12

5. STATUS OF WORKING AND PRODUCTION

The status of working of leases in the State as on 1.4.94 was as follows

District	Total no. of leases	No. of leases in operation.
Sundargarh		
Limestone	2	2
Limestone & Dolomite	37	18 (Limestone) 12 (Dolomite)
Dolomite	1	1
Bargad		
Limestone	3	2
Nuapada		
Limestone	3	3
Koraput		
Limestone	2	2
Malkangiri		
Limestone	1	Nil

The following statement indicates district-wise production of limestone and dolomite during the last 3 years :

('000 tonnes)

	Limestone			Dolomite		
	1991-92	1992-93	1993-94	1991-92	1992-93	1993-94
State	2,108	1,959	2,012	1,402	1,519	1,649
Districts						
Sundargarh	1,564	1,506	1,502	1,402	1,559	1,649
Bargad	502	395	442	-	-	-
Koraput	13	1	11	-		-
Nuapada	22	56	58	-		-

The major producing mines and the average annual production are as follows :

District	Lessee	Mine	Average annual production (in '000 tonnes)
Limestone			
Sundargarh	SAIL	Purunapani*	363
	Orissa Cement	Lanjiberna*	818
	B.S.L & Co.	Biramitrapur	147
	R.V. Enterprisers	Katang	96
Bargad	IDCOL Cement Ltd.	Dungri•	447
Nuapada	IDC of Orissa Ltd.	Dampala*	53
Dolomite			
Sundargarh	TISCO.	Gomardih*	440
	B.S.L & Co.	Biramitrapur	780
	R.V. Enterprisers	Katang	114
	A.N. Patnaik	Banki	93
	Tunmura-Jharbeda	V.K. Lal	57

(* Captive mines of the lessees)

6. USES AND SPECIFICATIONS

Limestone and dolomite are the principal raw materials for a wide range of industrial products.

Limestone is the principal raw material for manufacture of cement. Its other important use is as flux in the making of iron and steel including sponge iron and ferroalloys. Limestone is used for refining of sugar, as additive in glass industry, as a coating material in fertilizer industry, for manufacture of calcium carbide in paper and pulp industry, water purification, sewage treatment, alkali manufacture, removal of sulphur from stack emissions, stabilization of soil among others.

The uses of dolomite cover the areas of iron and steel, ferroalloys, alloy steel, glass, foundry, cosmetics and building construction. Besides flux, dolomite is used as an important refractory meterial.

The specifications prescribed for various end-uses of limestone and dolomite are described in the following statement.

	% CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3
Limestone					
Cement	42 (min)	4 (max)	14 (max)	1-2	2 (max)
Iron & Steel					
BF/Sinter	42 (min)	6 (max)	11 (max)		
SMS grade	49 (min)	4 (max)	4 (max)		
Chemical	50 (min)	-	2 (max)	0.25 (max.)	
Dolomite					
Iron & Steel					
BF	29 ± 1	19 (min)	6 (max)	2 (max)	
SMS	30 ± 1	19 (min)	3 (max)		
Glass	CaO +MgO	50%(min)	2.5(max.)		0.15 (max.)

While the various end-users desire to have the best quality raw materials for higher productivity, depending upon availability and cost, departures from the specified norms are often resorted to. For example, cement manufacturers can use limestone containing upto 5% MgO and 78% total carbonate.

With emphasis on higher productivity, the steel plants do not intend to use limestone with high alkali (more than 0.15%) and higher silica content (more than 3%). Availability of such fluxes being extremely limited, the steel plants have been importing limestone, the silica and total alkali contents of which are respectively less than 1% and 0.02%.

Limestone and dolomite produced in the State are being utilised mainly in the production of iron and steel, cement, ferro alloys and sponge iron. The cement industry of the State is dominated by plants of Orissa Cement Limited at Rajgangpur and IDCOL Cement Limited near Bargad., each of 3,000tpd capacity; and the 600tpd capacity plant of Snehadhara Industries near Sunki in Koraput district. Besides, as many as 24 mini cement plants of capacities ranging from 30 to 300 tpd have come up in the State, of which 21 are located in Sundargarh district. Minor uses of limestone in the State include manufacture of lime in small scale by burning of limestone and limeshells and as chips for building construction.

7. CONCLUDING REMARKS

In the earlier exploration programmes, the criticality of alkali content in limestone was not appreciated and large number of bore hole cores covering some of the major occurrences had not been analysed for alkali contents. It is therefore necessary to continue investigation in the known as well as unexplored deposits to delineate low silica and low alkali patches.

In the sinter for iron making, dunite or pyroxenite is preferred to dolomite as the former has higher MgO and lower alkali contents. This apart, with the phasing out of OH furnaces and adoption of BOF in steel making, the consumption of dolomite in iron and steel making is not expected to record increase, in spite of coming on stream new iron and steel plants in the State.

It is in the area of cement production that growth is expected. The prospects with proven potential that need to be developed include the Malkangiri and Sunki valley limestone deposits.

[The paper is based on the results of investigation carried out by the DMG, information available with the DMG and those furnished by OMC, IDCOL Cement, Tata Steel, Orissa Cement Limited among others.]

Manganese Ore

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1. INTRODUCTION

Manganese was recognised as an element in 1774 by the Swedish Chemist and apothecary, Scheele, whose fellow countryman, Gahn isolated the metal in the same year.

The average crustal abundance of manganese is slightly less than 1% (950 ppm). Although there are over 100 manganese minerals, the common ones are the following :

Mineral	**Composition**
Pyrolusite	MnO_2
Manganite	Mn_2O_3, H_2O
Psilomelane	MnO, MnO_2, $2H_2O$
Hausmannite	Mn_3O_4
Rhodochrosite	$MnCo_3$
Rhodonite	$MnSiO_3$
Braunite	$3Mn_2O_3$, $Mn\ SiO_3$
Hollandite	$(Ba, K)_{1-2}\ Mn_8O_{16}\ x\ H_2O$
Cryptomelane	$K_{1-2}\ Mn_8O_{16}\ x\ H_2O$
Jacobsite	$Mn\ Fe_2O_4$
Vredenburgite	$3Mn_3O_4$, $2\ Fe_2O_3$

2. GEOLOGY

Manganese deposits are widespread in the world's land areas; as oxide nodules on ocean floors, in lakes and other marine locations. In India, the deposits occur in Precambrian rocks in the Peninsular shield areas and are confined to several discrete belts or zones in the States of Andhra Pradesh. Bihar, Goa, Gujarat, Karnataka Maharastra, Madhya Pradesh, Orissa and Rajasthan.

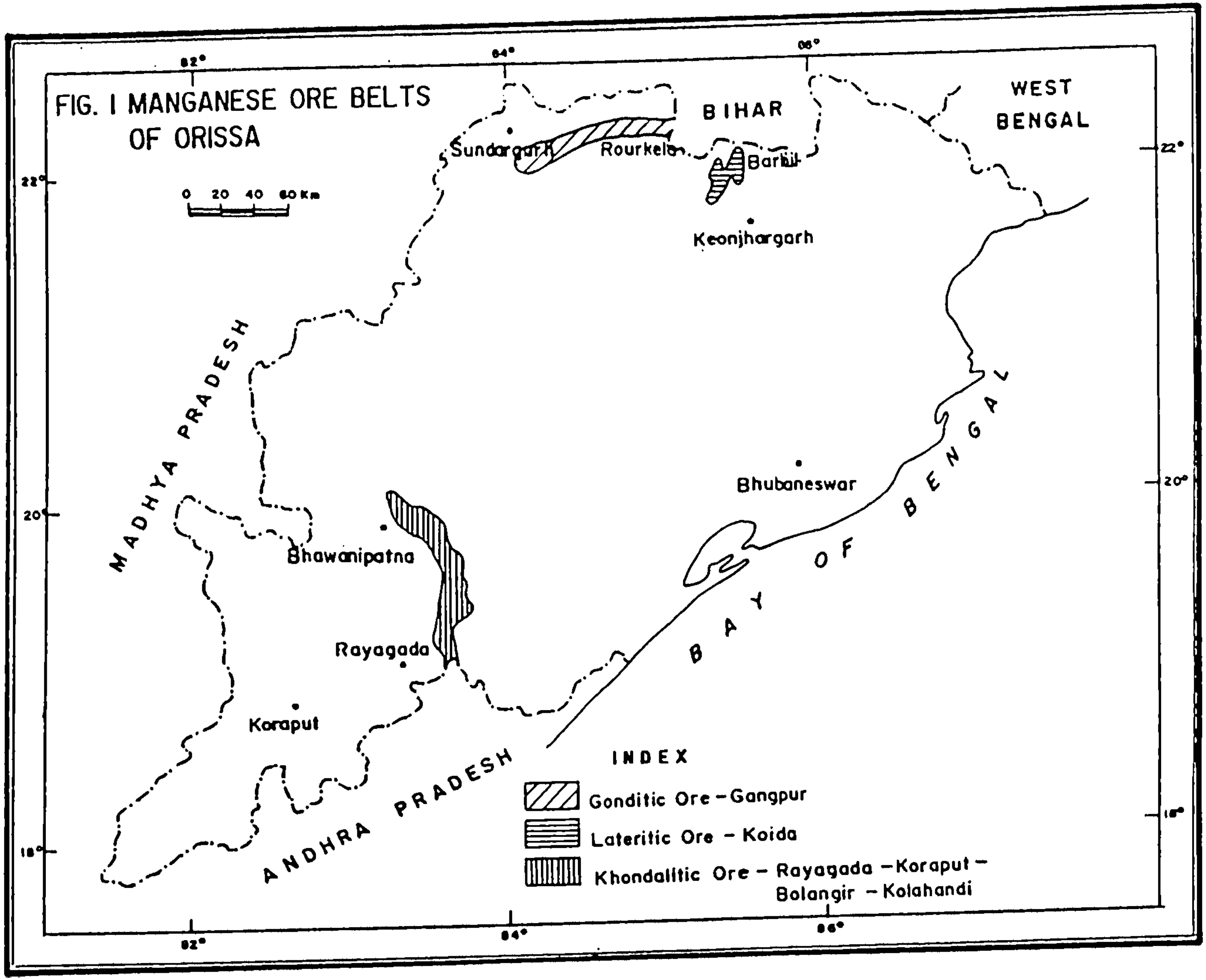

FIG. I MANGANESE ORE BELTS OF ORISSA

Based on geology, nature of occurrences and genesis, the deposits can be broadly classified as follows :

I. Stratiform deposits in metasedimentary rocks	a) associated with Gondites b) associated with Kodurites
II. Surficial and supergene deposits resulting out of weathering of manganiferous rocks	i) lateritoid ii) supergene enrichment and replacement in shales, schists and phyllites with associated BIF iii) enrichment of primary bedded deposits

Manganese ore deposits of Orissa occur in three distinct geological set-up, namely,

(1) Deposits in Bonai-Keonjhar belt associated with Banded Iron Formation of North Orissa belonging to Iron Ore Supergroup of Archaean age.

(2) Deposits associated with khondalites of South Orissa belonging to Eastern Ghats Supergroup of Archaean age.

(3) Deposits associated with Gondites of Gangpur group of Proterozoic age in NW part of Orissa.

These are described in the following paragraphs and shown in Fig. 1.

BONAI - KEONJHAR

Bonai-Keonjhar belt forming a part of synclinorium (60 km x 25 km) with a low plunge towards NNE, constitutes the most important manganese ore producing region of the country, characterised by occurrences of various grades of ore (from 25% Mn to dioxide) with low phos. content. The BIF, which broadly defines the outline of the synclinorium, is exposed almost continuously along the margins while manganese ore is confined to the top lateritised shale and lower lithomarge horizons in the core zone of the synclinorium. The major lithologic units of the area include BIF, Banded shales and Mixed Facies Formation of the Iron Ore Group. The lateritic cap ranges from 2 m to over 40 m in thickness.

The following broad stratigraphic succession has been worked out for this belt :

Kolhan Group	Sandstone, conglomerate and shale
———————— Unconformity ————————	
Iron Ore Group :	Mixed Facies Formation
	Banded Shale Formation
	Banded Iron Formation
	Volcanic Formation
	Basal Sandstone
———————— Unconformity ————————	
	Granite and gneisses with enclaves and rafts of metasedimentary and metabasic rocks

The Mixed Facies Formation comprising ferruginous shales and brecciated chert ranging in thickness from 30 m to 120 m hosts the manganese ore deposits confined to the upper 50-60metres. The lower part of MFF is composed of mainly variegated and white clay without any Mn-ore. Manganese ore occurs as pockets and pods within the top laterite profile; as thin bands and lenses within ferruginous shales and as ramifying veins in brecciated chert zones. High grade nodules of ores admixed with wad occur below the ore zone. Wad occurs finely interlaminated with white and pink clayey shale. The average manganese content in the wad is around 15%. Occurrence of manganese ore appears to be litho-controlled. Concentration of Mn-ore in brecciated zones is faults induced.

Recent studies have indicated manganese mineralisation in lower shales below BIF possibly of syngenetic origin. However, genesis of most of the occurrences in this belt is attributed to secondary enrichment of manganiferous shales and phyllites.

SOUTH ORISSA (Koraput - Kalahandi - Bolangir)

The manganese ore deposits of South Orissa comprising parts of Rayagada, Kalahandi and Bolangir districts are associated with Khondalite suite of rocks belonging to the Eastern Ghats Supergroup. The rock types include khondalite, quartzite and calc-granulites.

A generalised stratigraphic succession of the lithounits of the area is as under.

Soil and alluvium
Laterites
Granite, granite gneiss
Migmatites
Charnockites (acid to intermediate)
Khondalite and its variants
(Khondalite, Quartzite, Mn- quartzite, Calc-granulites and Mn- ore)

The lithounits are migmatised and garnet is a constituent in all the rock types. Three phases of folding have been deciphered in the area. Bedding is rare but banding is common. Manganese ores occur in three stratigraphic horizons in the khondalites which have been weathered (often kaolinised) and sheared.

i) at or near the junction of khondalite with calc-silicate rock,
ii) at or near or within khondalite and
iii) at or near the junction of khondalite with quartzite

Of all the deposits in South Orissa, Nishikhal in Rayagada district held under lease by Orissa Mining Corporation and under active mining, is the most important from the point of view of reserve and development potential. A brief description of Nishikhal deposit is presented.

Nishikhal

There are three distinct ore bands, associated with khondalite suite of rocks, extending for a strike length of about 2 kms in a NNE-SSW direction with sub-vertical easterly dips (Fig 2). The ore bodies have been proved down to a depth of 100m. from the surface. The Precambrian metasedimentary sequence is represented by khondalite, quartzite, manganiferous quartzite, calc-granulite and associated manganese ore bodies. These rock types have been metamorphosed under granulite facies condition, permeated by quartz-felspar neosomes and pegmatites and affected by folds. The dominant ore and associated minerals are psilomelane, cryptomelane, pyrolusite and goethite. The ore has been formed by supergene enrichment of primary syngenetic metamorphosed assemblage. Phosphorus is present as a discrete mineral phase in the form of apatite contained in the silicate minerals as well as fixed in the crystal structure of goethite, cryptomelane and psilomelane.

A GENERALISED GEOLOGICAL MAP OF NISHIKHAL MANGANESE ORE DEPOSIT

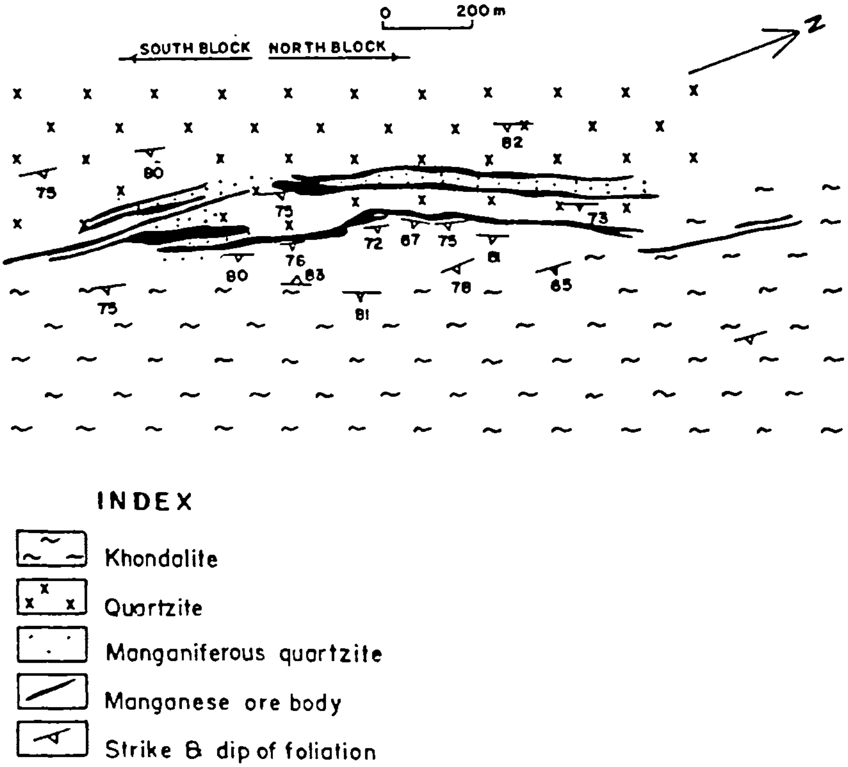

Fig. 2

Nishikhal ores occur as streaks, lenses, bands, veins and discontinuous linear bodies conformable to the major foliation of rocks. Occurrence of well -defined ore bands in sharp contact with khondalite and quartzite indicates their formation as chemical precipitates in the depositional basin.

Nishikhal is probably the single largest ore deposit in the State with a reserve of 10.2 million tonnes. Analysis of a few representative samples indicate the following range :

Mn :28-38%, Fe: 10-15%, SiO_2 : 3-11%
Al_2O_3 : 3-5%, P :0.3-0.4%, Na_2O :1.3 - 2%, K_2O : 0.08 - 0.13%

Nishikhal ore is being utilised in iron and steel making by Visakhapatnam Steel Plant, which can treat high phos ore by blending as well as directly in the blast furnace.

The other important deposits in this belt, located south of Nishikhal are Podkona-Taldoshi (7 million tonnes), Kuttinga-Devjholla (under investigation), Karajhola and Renga-Gatiguda. The occurrences north of Nishikhal are at Kinchikhal, Koka, Liligumma and Dulki. These occurrences excepting those in Podkona - Taldoshi, Kuttinga-Devjholla are not of much economic significance. In Dungripali-Balgdungri area of Bolangir district, four manganese ore zones having lengths and widths varying from 1-2 km and 2-15 m respectively associated with quartzite and calc-silicate rocks have been delineated.

GHORIAJHOR AREA, SUNDARGARH DISTRICT

Manganese bearing gondite of Ghoriajhor Formation is the youngest horizon occurring in the core of Gangpur synclinorium and confined to the central part of the Gangpur group of meta-sedimentaries. The manganese belt is nearly 60 kms long, dotted with old workings abandoned at shallow depths of which only about 10 km stretch has been explored including drilling. The rock types include gondite with manganese mineralisation, mica schist and phyllites. The general trend of the rocks is N 35°-55° E-S 35°-55° W with 15° - 35° dip towards south-east. Manganese ore concentration in the form of bands, lenses, veins, disseminations and pockets is noticed along plunges of minor to mesoscopic folds in gondites.

3. EXPLORATION

Exploration techniques unique to terrestrial deposits of Mn-ore do not exist. Geophysical and geochemical methods are also not sufficiently selective for Mn-ore. Interpretation of regional geology, detailed geological mapping, trenching, pitting, drilling and trial mining have in general, constituted the inputs for exploration and assessment of Mn-ore occurrences.

The organisations involved in carrying out systematic exploration for Mn-ore in Orissa include the Geological Survey of India, Tata Iron and Steel Company Limited, Orissa Mining Corporation and the State Directorate of Mining & Geology. Indian Bureau of Mines also conducts examination of mines. Limited exploration has been carried by Aryan Mining & Trading Corporation, OMDC and Rungta Group in their leaseholds.

Exploration activities also include examination of abandoned mines, quarries, old pits and sampling of dumps.

Based on the survey carried out by different organisations, the following general observations can be made;

i) No thumb rule can be laid down for exploration of Mn-ore deposits.

ii) In Bonai-Keonjhar area in Orissa, Mn-ore has been found to have been localised along the hinge of the anticlinal part of the folded shales, which are lateritised.

iii) Electrical resistivity technique adopted by TISCO in their leasehold in Orissa has not been indicative. Perhaps, wider electrode spacing would indicate anomalies of significance.

iv) A 25m square grid pattern of drilling has been adopted by TISCO in their leaseholds in Orissa.

v) In the "Horse Shoe" iron ore basin of Orissa & Bihar, Mn-ore deposits are confined to the Lower Shales and BIF is the roof formation for Mn-ore bodies.

4. RESERVE

The recoverable reserves of manganese ore (25% Mn and above) in India, as on 1.4.90 are estimated at 176 million tones. The conditional resources (-25% Mn) are estimated at 2 million tonnes.

The State-wise break-up of reserves is as follows

	(in million tonnes)
Andhra Pradesh	7.53
Bihar	2.30
Goa	23.56
Gujarat	1.48
Rajasthan	0.41
Maharastra	19.17
Madhya Pradesh	16.54
Orissa	40.84
Karnataka	64.55
West Bengal	0.10

Approx. grade-wise (rather end-use) break-up of reserves of manganese ore in Orissa is as under :

Chemical/battery	: 0.73	(0.16)
FeMn	: 4.04	(0.7)
Medium	: 5.1	(0.5)
BF	: 25.86	(3.4)
Unclassified	: 4.6	(0.06)
Not known	: 0.5	

(Note Figures within brackets indicate "proved reserves". The reserve figures are based on Indian Minerals Yearbook, 1993)

Sector-wise break-up of reserves established so far is as follows

1. Bonai-Keonjhar	17.20 million tonnes in parts of the belt and excluding reserves contained in the leaseholds of TISCO, OMDC, Bolani Ores Mines and a few others.
2. Ghoriajhar-Laingar area in Sundargarh district	Not estimated
3. South Orissa :	
a) Nishikhal-Taldoshi block	17.96 million tonnes
b) Kuttinga-Devjhola	1.16 " "
c) Bolangir-Kalahandi deposits	Not estimated

On completion of the exploration programme in the three sectors, there is distinct possibility of the State's reserve exceeding 50 million tonnes.

5. MINING, PRODUCTION AND BENEFICIATION

The first reported manganese ore mining in the State dates back to the year 1924 when M/s United Steel Corporation of Asia Limited started working Thakurani deposit in Keonjhar district. The mine is now being worked by Orissa Mineral Development Company. Mining operations in the State are opencast, dominated by the age old compressor- pneumaticaly operated rock drills for drilling and blasting, pick and shovel. In some of the mines operated by TISCO., OMC, AMTC, OMDC, dozers, payloaders, hydraulic excavators, shovels and DTH drills are being deployed. The benches are usually of 1.5m height. Dumpers and tipper trucks are used for haulage.

Orissa is the leading producer, accounting for about 35% of the total production of manganese ore of the country.

There were as many as 36 mining leases for manganese ore and 61 for iron and manganese ores subsisting in the State as on 1.4.94. Of these, 31 and 39 leases were in operation. The district-wise break-up of leases is as follows

	No. of Manganese ore leases	**No. of Iron & Mn-ore leases.**
Keonjhar	14 (11)	38 (25)
Mayurbhanj	1	(1)
Rayagada	3 (2)	
Sundargarh	19 (18)	22 (13)

(Figures within brackets indicate number of manganese mines in operation)

Production of manganese ore in the State during the last three years have been of the following order :

(in '000 tonnes)

	1991-92	**1992-93**	**1993-94**
Dioxide	8.4	9.3	11.7
+ 46% Mn	47.4	53.3	57.1
+ 35% Mn	72.3	89.3	102.7
+ 25% Mn	491.0	549.0	497.7
- 25% Mn	0.5	0.6	-
	619.6	**701.5**	**669.2**

District-wise production break-up during 1993-94 was as under

	Dioxide	+46%Mn	+ 35%Mn	+ 25%Mn
Keonjhar	9	38.9	70.5	390.4
Mayurbhanj	-	-	-	0.4
Rayagada	-	-	0.13	23.2
Sundargarh	2.7	18.2	32.0	83.8

It is observed that low grade (-35% Mn) ore constitutes about 74 - 80% of total production of manganese ore in the State. Production from Keonjhar and Sundargarh district, which constitute about 96% of the State's production are characterised by high iron and low phos (less than 0.1%) contents. Production from Rayagada district, almost exclusively restricted to Nishikhal mine of OMC, is high in phos (average 0.35%) and the Mn content ranges from 28 to 42%. The major producers of manganese ore in the State are Orissa Mining Corporation, Tata Iron & Steel Company, Aryan Mining & Trading Corporation, Orissa Mineral Development Company, Orissa Manganese & Minerals Private Ltd. and Rungta Mines Private Limited.

The major producing mines of the State are listed in the following table :

District	**Lessee**	**Mine**	**Average annual production (in'000 tonnes)**
Keonjhar	TISCO	Joda West	25
	OMC	Dubna	24
		Seremda-Bhadrasahi	25
		S.G.B.K	45
		Dalki	20
	OMDC	Bhadrasahi	28
		Belkundi	40
	BPMEL	Dalki	35
	Rungta Mines	Siljora-Kalimati	50
Sundargarh	OM&M	Patmunda	37
		Orahuri	23
	TISCO	Malda	25
Rayagada	OMC	Nishikhal	20

Exports of manganese ore during the last 5 years have been of the following order :

	('000 tonnes)
1989-90	22
1990-91	3
1991-92	15
1992-93	-
1993-94	21

Production generally conformed to the specifications of the iron and steel, chemical and ferroalloys industries.

There is considerable variation in the grades of manganese ore in a particular deposit. The practices adopted for processing and beneficiation include crushing, jigging, screening, hand picking and sorting. Blending of ores is often resorted to produce ores of desired grades. In South Orissa ores and more specifically in Nishikhal deposit, as most of the phosphorous is held in adsorption in goethite as well as manganese phases apart from apatitic association, reduction in phos. content can be affected by alkali leaching or roast-alkali leaching methods.

6. USES

Manganese, a hard brittle greyish white metallic element, was first used for colouring glass and pottery. Its use in iron and steel making dates back to 1830s.

Manganese is essential to the production of iron and steel, where it is used in the form of ore (for production of hot metal / pig iron) as well as in the form of ferro manganese / silico manganese (for production of steel), About 95% of total production of Mn- ore is used in iron and steel production where it functions as a de-oxidizer and de-sulphuriser; improves the strength, toughness, hardness, resistance to wear, hardenability of steel; inhibits formation of embrittling grain boundary carbides.

There is no satisfactory substitute for manganese in its above functions.

Manganese content of steel, averaged over all grades is about 0.7%.

The other lesser but important uses of manganese are in production of aluminium and copper alloys where it improves corrosion resistance and electrical resistance. Mn-bronzes are used for marine propellers and fittings, gears and bearings. High co-efficient of thermal expansion properties possessed by high Mn content alloys are used in bi-metallic elements of thermostats.

Manganese ore (oxide) is used as an oxidant in the production of hydroquinone, in the leaching of uranium ores in the electrolytic production of zinc; manganese compounds as soil conditioners, water purifiers and for colouring; in the manufacture of welding rod coatings and fluxes, manganese -rich ferrites for electronics.

A distinctive and well known use of manganese in the form of dioxide (battery grade ore) is in the manufacture of carbon-zinc dry cell, where it participates in the electrochemical reaction.

7. CLASSIFICATION AND SPECIFICATIONS

Classification of Mn-ore is not based on Mn content alone. Phos. content and Mn/Fe ratio are equally important. Classification has been made for the purpose of royalty, customs duty, trade etc. The basis also varies from country to country. It is therefore difficult to evolve a uniform system of classification.

In India, for the purpose of assessment of royalty, Mn-ore has been classified into the following grades :

(a) Mn dioxide
(b) 46% Mn and above
(c) 35% Mn and above but less than 46%Mn
(d) Below 35% Mn and above 25% Mn.

Another classification, which almost follows the above basis, grades Mn-ore as,

Battery grade	MnO_2 by mass (dry basis)	72%	min.
	Fe	7%	max.
Chemical grade	MnO_2	75%	min.
	Fe	1.5%	max.
Ferro-grade	Mn	46%	min.
	Mn/Fe	4.6	min.
	P	0.2	max
Medium grade	-46 +35% Mn		
BF grade	Mn	25-35%	
	Al_2O_3	7.5%	max.
	SiO_2	13%	max
	P	0.2%	max*
	Size	10-40	mm

(* IS 11281 - 1985 specifies P content upto maximum 0.35%)

8. CONCLUDING REMARKS

Exploration involving drilling carried out by the Geological Survey of India in the three known manganese ore belts of the State, viz., Bonai-Keonjhar, Southern and Western Orissa and the Ghoriajhor sector have led to establishment of over 40 million tonnes of reserve. On completion of drilling programme in the remaining leasehold and potential area of Bonai-Keonjhar, Kuttinga-Devjhola and other blocks in Rayagada and in Bolangir districts, and the unexplored portion of Ghoriajhor belt, there is distinct possibility of substantial augmentation in the resource position.

With developments in iron and steel making technology, specific consumption of manganese ore has been declining. While there is some shortage in the availability of ferrograde ore, reserves of BF grade ore in the State are quite adequate.

Attempt should be made for assessment of bi-metal ores of Bonai-Keonjhar sector, which have good utilisation potential in iron making. 'Wad', a manganiferous material of about 40% (Mn + Fe) and less than 0.1% phos. should also merit more than academic attention, particularly possibility of its economic beneficiation.

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Tin Ore

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1. INTRODUCTION

As a major ingredient of tinplate and solder, use of tin is well known. Tin is rarely used in its pure form. It is either alloyed with another metal or coated upon another metal. The only mineral of commercial importance as a source of tin is cassiterite (SnO_2), theoretically containing 78.6% tin and 21.4% oxygen. Fe_2O_3 and Ta_2O_5 are found in the crystal lattices as impurities. Cassiterite has a high specific gravity of 7, a Moh's scale of hardness of 6 to 7, usually dark brown or black in colour with an adamantine lustre.

Tin is a relatively scarce element with a crustal abundance of 2 to 3 ppm. Cassiterite is a high temperature product of magmatic crystallisation and shows an affinity for granitic rocks or their extrusive equivalents. Because cassiterite is both heavy and chemically inactive, it tends to be concentrated in residual placers that form over or adjacent to bedrock source areas where weathering and erosional processes remove lighter materials and concentrates heavier materials by action of gravity. Most of the world's tin is produced from placer deposits and the richest placers are found in stream deposits.

The major deposits are in Malaysia, Indonesia, Thailand and Bolivia, which account for bulk of world tin production. The other important tin producing countries include Brazil, U.K, former USSR, China, Zaire, Nigeria and Republic of South Africa, Germany, Myanmar and Zimbabwe. In India, tin occurrences are confined to Bastar district of M.P and Malkangiri district of Orissa. Primary tin mineralisation has been reported from the gneissic terrain near Tosham in Haryana.

2. GEOLOGY

The tin bearing area in Malkangiri district of Orissa is occupied by meta-sedimentaries consisting of phyllites, gneisses and schists belonging to the Proterozoic Tulsidongar Formation and overlain by Bailadila BIF. These have been intruded by sills and dykes of partly metamorphosed dolerites and amphibolites. Swarms of pegmatites have traversed the meta- sediments - metabasic ensemble. Granitic invasion is seen in the southern, south -western and north-western parts of the area.

The mineralisation is associated with acid pegmatites. The metallogenetic setting of the stanniferous pegmatites of Orissa has been across the regional NE-SW trend of the Eastern Ghat Mobile Belt (EGMB), within which the pegmatite province has a mutually cross-cutting relationship.

3. TIN ORE OCCURRENCES OF ORISSA

Occurrence of cassiterite was first located in Mundaguda-Salimi area of Malkangiri sub-division (now district) by the State Directorate of Mining & Geology during 1974. The area bounded by Bhimsen river in the west (marking Orissa-M.P boundary), Sarangpalle village in the east, Kolab river flowing westwards in the south, Lokti and Tulsidongar in the north measures approx. 170 km². However, mineralisation has been recorded beyond this area south of Kolab river. Jeypore, nearest town in Orissa is located at a distance of about 80 kms (via Mattili). The tin-bearing terrain is almost flat, interspaced with small mounds of metabasics and pegmatites. The average elevation of the Quaternary terrace is 230m above MSL.

Primary cassiterite occurs in the form of veins and specks in pegmatites with varying amounts of columbium and tantalum. Some of the pegmatites are lithium and beryl bearing.

Cassiterite occurring in the colluvial and eluvial placers off the stanniferous pegmatite sources are mostly confined within a depth of 2 metres from the surface, the thickness of the soil mantle ranging from 0.10 to 1.0 metre. An area of about 2km² between Mundaguda and Kurumpalle and more specifically around Mundaguda was found to be of significance.

Other occurrences

(1) Confluence of Ong and Mahanadi

Panned heavy concentrates from pegmatites and vein quartz emplaced in granitoid foliation have shown tin values of upto 0.5%.(Ref : SGPB Proceedings, 1988).

(2) Confluence of Tel and Mahanadi

Pegmatites within the granite have gemstones along with tin, tungsten, Cb-Ta in dispersion around. Pegmatite samples collected by DMG, Orissa on analysis have indicated 1,000 - 1,500 ppm tin, 75-200 ppm W, 200 ppm each of Nb_2O_5 and Ta_2O_6. Incidence of Nb and Ta at 40 to 800 ppm per 100 Kg of colluvial material has been reported.

(3) Area between Amuda and Manmunda, Bamunda and Karunapalli, Boudh district

Some zoned and rare -earth bearing pegmatites have been delineated. These indicate potential for tin mineralisation as well as those of Nb, Ta and W.

Quartz, cleavlandite, muscovite, biotite, lepidolite, beryl, tourmaline, columbite - tantalite constitute the major constituent minerals in the pegmatites of the area along with cassiterite.

As many as 139 pegmatite bodies of varying dimensions have been located within an area of 70 km². Of these, 12 are located south of Kolab river. Only 38 out of 127 located north of Kolab river and one out of 12 (south of Kolab) have been found to be tin-bearing. The DMG has located as many as 260 pegmatite bodies in an area of 170 km² between Mundaguda and Salimi. The important locations are Mundaguda, Dammoguda, Pedapada, Mohopodoro and Permarasu.

Basing on the incidence of tin mineralisation, the following features have been observed

a. Pegmatites emplaced into Bengpal metasediments, exposed along Kolab river elongated in a E-W direction are devoid of tin mineralisation. One pegmatite traversing the Bengpal metasediments about 1 km east of Mundaguda indicated 0.06% cassiterite - an unique feature in a schistose country.

b. Pegmatites emplacing the metabasites between Bhimsen river and Dammoguda through Mundaguda, Mohopodar and Permarasu are tin bearing.

c. The albitised portions of the pegmatite contain good concentration of cassiterite - suggesting pneumatolytic genesis.

d. Pegmatites containing cleavlandite and lepidolite are richer in cassiterite.

e. Cassiterite is associated with greissens

4. EXPLORATION, RESERVE AND GRADE

Exploration carried out by the State Directorate of Mining & Geology and G.S.I. comprised large scale geological mapping (1 25,000/ 5,000/ 1,000), trial excavation, drilling, colluvial and stream sediment sampling and panning. G.S.I. carried out limited drilling while MECL did some trial excavation. Orissa Mining Corporation had carried out exploratory mining and panning to recover cassiterite concentrates.

According to IBM, the reserves estimated as on 1.4.90 are as follows

	Ore	**Metal**
All India	28.91 million tonnes	3,271 tonnes
Bastar (M.P)	28.89 million tonnes	3,236 tonnes
Malkangiri (Orissa)	12,692 tonnes	35 tonnes

As per exploration conducted by the DMG, Orissa, reserve of 223 tonnes of tin concentrates has been estimated in the colluvial zone in Mundaguda covering an area of about 207,000 m^2. Sn content in the cassiterite has been found to be about 70% and its incidence ranges from 200 gms to 4.5 Kg per tonne, confined to a depth of 1m from the surface. A reserve of 30 tonnes of tin concentrates as primary in pegmatites has been estimated in Mundaguda block in addition.

An area of approx. 1 km^2 around Dammoguda has been examined and incidence of cassiterite in placers is found to be 600gm / tonne. Analysis of a few samples of metabasics from Tentuligumma and Bajaniguda reveal incidence of Sn, Ta and Nb to be ranging from 50 to 400, 500 to 800 and 100 to 600 ppm respectively.

5. MINING AND PROCESSING

The principal methods for mining placer deposits are bucket- line dredging, gravel-pump operations and hydraulicking. The latter two methods use water jets to dislodge tin bearing material and riffled launder for washing.

Processing of crude tin concentrates involves crushing, grinding, screening, classification, jigging and tabling. Magnetic or electrostatic separation is also used. Pegmatite bulk samples from the Mundaguda area subjected to tabling at -20# size free from magnetics showed 500 to 7,500 gm/tonne of concentrates though results of 150 ppm have been achieved in the field level beneficiation tests. Calculating back, the pegmatite raw grade averages 0.1% Sn, ranging from 0.03 to 0.51% Sn.

Orissa Mining Corporation carried out mining of a few stanniferous pegmatite bodies and colluvial placers in Mundaguda sector. OMC also purchased tin ore concentrates, not necessarily all originating from Orissa. A total quantity of about 84 tonnes of concentrates had been produced till the end of 1992-93 since the operations started in 1982-83.

During the said period, purchases amounted to 123 tonnes. The average tin content of the concentrates produced and purchased was 65%.

6. PROSPECTS

Exploration of the potential tin bearing areas in the State is far from complete. The tin prospects assume importance in view of the associated rare metals in stanniferous pegmatites and placers, namely, niobium, tantalum, lithium, beryllium and tungsten.

The coarse and fragmented laterite patches west of Rengabeda, east of Mundaguda, near Kumarpalle north of Gurupada and Mohopodoro and the moorum profile near Dammoguda need to be explored for recoverable tin values.

The other prospects which need to be examined include gold and andalusite.

The burried and old river courses are potential targets for exploration in Malkangiri drainage system.

M/s Hindustan Alloys Manufacturing Co. has been granted a Prospecting Licence for tin and associated minerals in Mattili block of Malkangiri district. The Company has proposed to set up tin ore processing and smelting unit in the area.

Vanadium Ore

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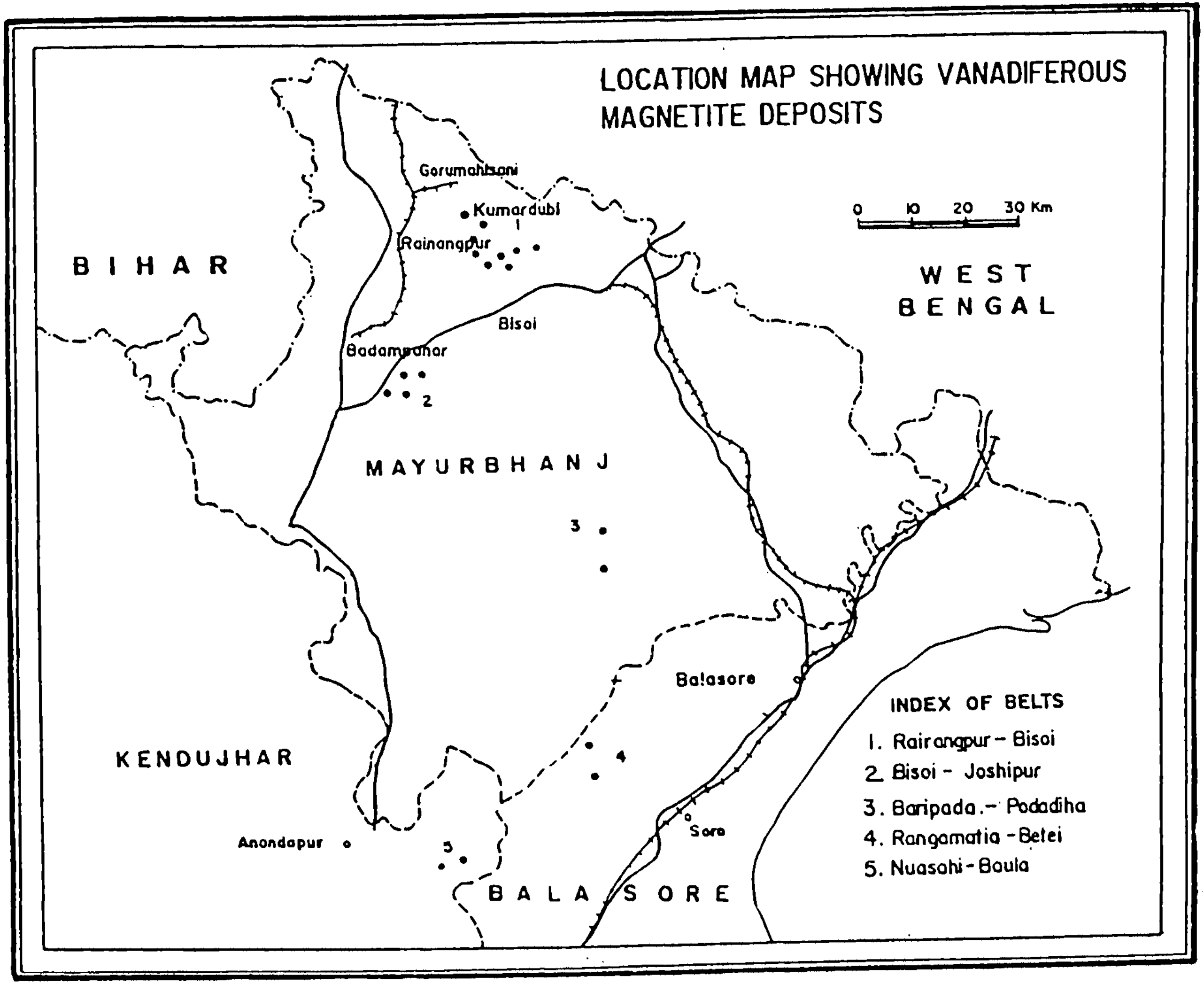
1. INTRODUCTION

Vanadium is an important alloying element. Addition of small amount, often less than 0.1% to steel and cast iron can significantly increase their strength, toughness and ductility. The only potential ore in India from which vanadium can be extracted is the vanadium and titanium bearing magnetite. There is no production of this ore in this country. Indigenous availability of vanadium is confined to the byproduct sludge of alumina plants.

The first attempt to produce vanadium in the form of ferro-vanadium was made by the Mayurbhanj Durbar administration way back in 1943-46 on the basis of availability of vanadium bearing magnetite at Kumardubi and Betjharan. The proposal has been pursued intermittently sans materialisation. Orissa Mining Corporation held a mining lease over Kumardubi and Betjharan deposits covering an area of 1346.80 hectares.

2. GEOLOGY

Magnetite associated with gabbro-anorthosite suite of rocks contain vanadium and titanium and occur at several locations in Mayurbhanj district with V_2O_5 content varying from less than 0.5% to 2%. S.V.P. Iyengar of G.S.I is credited in bringing these occurrences into limelight in the course of geological mapping during 1951-58. Vanadium bearing magnetites had also been recorded near Boula in Keonjhar district by S.K. Baruah and Prasad Rao (1948-50), near Godasahi and Rangamatia in Balasore district by H. Nandi. Map enclosed shows the distribution of deposits.



LOCATION MAP SHOWING VANADIFEROUS MAGNETITE DEPOSITS

A broad **stratigraphic** profile of the vanadiferrous magnetite bearing rocks is projected as under.

Recent to sub-recent		Soil and Alluvium laterite, pebble bed.
	Newer Dolerite	Dolerite
	Singhbhum granite	Pegmatite and quartz vein
		Granite & granite gneiss
Precambrian		Gabbro-anorthosite suite of rocks with magnetite lodes.
		Ultramafic rocks with chromite bodies.
	Iron Ore Group	Banded iron formations with iron ore, quartzite and conglomerate, lava, epidiorite and hornblende schist.
		Older metamorphics.

The gabbro-anorthosite suite of rocks occurring in the area are the host rocks. The magnetite lodes occur as pockets, lenses and stringers in the host rock.

3. OCCURRENCES

Systematic geological mapping carried out by the Geological Survey of India and the State Directorate of Mining and Geology over the years has led to delineation of a number of vanadium bearing magnetite occurrences.

These can be broadly grouped into five geographical belts, namely,

a) **Rairangpur - Bisoi**

(includes deposits at Kumardubi, Betjharan, Amdabeda, Gargari, Kunjakocha, Bhangapahar, Hatichar)

b) **Bisoi-Joshipur**

(includes deposits at Mayurbeka, Kesham, Dhulabeda, Sialnoi, Asanbani, Bariadihi, Kundabari).

c) **Baripada-Podadiha**

(includes deposits at Bahalda, Andipur, Chitrabania)

d) **Rangamatia - Betei (Godasahi)**
(deposits at Rangamatia and Godasahi)
e) **Nuasahi-Boula**
(deposits around Nuasahi and Boula)

A brief description of some of the important deposits follows

Kumardubi (22°17' 86°19')

The deposit which is the most important, lies to the west of Kumardubi village. It occupies an area of about 0.25 sq. km. containing in situ ore bodies and float ore. 10 ore bodies have been delineated in this area. The float ore occurs to the south of the in situ exposure along the slope of the hills. The ore bodies occur in a hilly terrain in Kanapat hill range south of Gorumahisani with altitudes ranging from 550m to 750m aMSL.

The thickness of ore as intersected in the bore holes varies. The pure ore band occurs interbanded with disseminated ore or with the basic rock. Distinct gradation could also be noticed from pure band of ore to pure gabbroic rock with all intermediate variations.

From the study made so far, no regular pattern in the distribution of vanadium values could be established.

Betjharan (22°15'20" 86°19'10")

The deposit lies north-east of Betjharan village. As many as 16 large and small seggregated vanadiferrous magnetite bodies occur in the area. The central portion of the area shows a continuous ore body with an E-W strike. The thickness of ore body varies from 3 to 36m. An extensive float zone surrounds the main ore body.

Amdabeda (22°14' 86°20')

The deposit occurs to the south of village Amdabeda. There are three veins of magnetite in this area and they are close to each other. Considerable area covered under float surround the veins.

Gargari (22°12' 86°23')

This deposit in the form of several veins occurs to the south west of village Gargari. These magnetite bodies are surrounded by clusters of hematite and limonite.

Kunjakocha (22°13' 86°23')

The vanadiferrous magnetite deposits occur east of Kunjakocha village in the Tungru hill range. There are two main ore veins surrounded by smaller veins. This deposit is partly concealed under gabbroic rock.

Bhangapahar (22°13'30": 86°24') & **Judia** (22°13' 86°24')

These deposits occur west of village Hatichar in the Tungru hill range. There are two main ore veins and two minor veins in this area along with considerable float ore.

Hatichar (22°13' 86°24'30")

These deposits occur to the east of village Hatichar in the Tungru hill range. The main ore body occurs as a ridge and extends over a length of 265 m with varying width of 15-20 m. There are a few other ore bodies in the area occuring to the east and north of the main ore body.

Bisoi-Joshipur

The Bisoi-Joshipur belt runs parallel to the eastern margin of Simlipal hill range. The deposit occuring south-west of village Mayurbeka (22°1' 86°12'30") is important. Other small and scattered ore bodies occur around Kesham, Dhulabeda, Sialnoi, Asanbani, Bariadihi and Kundabari.

Baripada-Podadiha

Small occurrences of vanadiferrous magnetite are noticed around Andipur (21°57' : 86°05'), Bahalda (21°47' : 86°33') and Chitrabania (21°35' : 86°27').

Nuasahi-Boula

The Fuljhara deposit (21°18'15" : 86°19'15") includes discontinuous magnetite lodes which extend in a east-west direction. The trend changes to N 72° W towards the east, dipping steeply due north.

Several other small magnetite lodes are also encountered in the area.

Rangamatia (21°29' 86°39')

Two small magnetite pockets occur in the eastern and southern slope of Rangamatia Pahar. These occurrences are mainly of lenticular shape extending in length from 20 to 30 m. Most of the abandoned pits and trenches cover the extension of these deposits.

The south slope is covered with ferrogabbro. The eastern slope of the mound is covered with thickly dispersed float ore.

Betei (21°24'15" 86°30'12")

The Betei deposit includes 9 numbers of magnetite lodes located south of Betei village and near the road side on way to Godasahi. These magnetite lodes are of lensoid type and trend from N70°W-S70°E to N50°E-S50°W. The dimensions are 150m (length) X 13m (max. width) and 2.5m (average width).

4. EXPLORATION, RESERVE AND GRADE

The State Directorate of Mining and Geology and the Geological Survey of India carried out detailed exploration during the periods 1962-75 and 1972-74 respectively to prove the reserves and grade of the important deposits. The methods comprised,

a) large scale mapping including plane table mapping,
b) contouring,
c) trial excavation,
d) drilling,
e) collection of bulk samples for metallurgical tests and
f) sampling.

Detail proving operations were confined to proving of reserves and grade of Kumardubi and Betjharan deposits. In Kumardubi, drilling at 15-20m interval was undertaken totalling 2,433m in 64 bore holes. In Betjharan, 51 boreholes had been drilled involving 1,518 meters. B.H. cores were sampled corresponding to every metre run and samples were collected from excavated materials from pits/trenches corresponding to each metre depth. The samples were prepared for analysis by powdering to 80 mesh size.

Reserve has been computed by area of influence, cross section and isopach methods. Weighted % of V_2O_5 of different run/pit/trench depth were determined by multiplying assay values with the thickness of that particular ore horizon. The average grade of ore body has been calculated from the average grade of each cross section /influence of B.Hs/pits/trenches computed to the volume.

The inventory prepared by I.B.M. places the total reserve of vanadiferrous titano-magnetite ore in India as on 1.4.90 at 13.33 million tonnes and metal at 20,287 tonnes. For Orissa, the figures are 2.53 million tonnes and 5,845 tonnes. However, the reserves of V.M ore estimated by the Directorate of Mining & Geology for Orissa are of the following order :

	(In million tonnes)	% V_2O_5
Kumardubi	1.20	Average 1 at 0.7 cut-off
Betjharan	0.80	
Amdabeda Gargari Hatichar Mayurbeka Kunjakocha Bhangapahar Bahalda, Andipur Chitrabania	1.40	0.6-1.5
Boula-Nuasahi	0.57	0.1-0.5
Betei-Rangamatia	0.02	1.4

The range of constituents of the VM ore of Kumardubi and Betjharan are as follows :

	Kumardubi	**Betjharan**
% Fe	55-60	55-60
% V_2O_5	0.8-1.3	1.0-1.4
% TiO_2	11.5-13.5	10-12
% SiO_2	0.5-1.5	0.5-2
% Al_2O_3	1-3	2-5

5. MINERALOGY

The minerals present in the ore as identified under the microscope on the basis of optical criteria, etch reactions and microhardness tests are titanomagnetite, magnetite, ilmenite spinel. ulvospinel, martite, hematite, goethite, lepidocrocite, rutile, pyrite, chalcopyrite, pyrrhotite and covellite. The magnetite and ilmenite form the bulk composition of the ore. The mineral coulsonite $(FeV)_3 O_4$, responsible for the vanadium content of the ore, is not identified under ordinary magnification. Under high magnification and oil emersion, bluish clusters are seen in the main magnetite crystals which may be coulsonite. X-ray studies failed to identity the coulsonite grain probably because of its presence in traces and its identity in crystal habit with magnetite. However, the presence of coulsonite is confirmed by microchemical test.

6. ORE CHARACTERISTICS

The ore is essentially dark grey to black in colour and massive to crystalline in character. It is highly magnetic and possesses a metallic lustre. Fragile hematitic ore is also seen at places. In hand specimen, the minerals magnetite and ilmenite are separately identified. The specific gravity of ore varies from 4.4 to 4.8.

Iron and titanium form the main constituents of the ore and they contribute about 90-95% of the weight of the ore in the form of oxides. Other constituents of ore are silica, alumina, magnesia, phosphorous, sulphur and vanadium. The content of vanadium in the ore is quite variable and no regular pattern in the distribution of vanadium values could be established in a single ore body. A typical analysis of the ore is as follows :

Fe	59.98 %
SiO_2	0.56 %
Al_2O_3	3.26 %
TiO_2	11.60 %
V_2O_5	1.40 %
MnO	0.37 %
MgO	0.30 %
P_2O_5	Trace
CaO	Nil
SO_3	Nil
Combined Water	0.05 %

7. GENESIS

Banerji (1984) opined that the iron-titanium oxide ores of Kumardubi and Betjharan had crystallised at a lower temperature range i.e. between 600° C and 800°C. Petrographic studies of the associated rock types reveal that the bulk of the iron-titanium oxide minerals are intercumulus in nature and crystallised later than the plagioclase feldspars and pyroxenes. The oxides are invariably having reaction rims of secondary biotite, amphiboles and at places chlorite in contact with the earlier silicates. The presence of water and volatile materials seem to have played a very important role in keeping these refractory oxides molten for an appreciably long period. The rock types also show extensive deuteric and hydrothermal alteration in as much as in some places the pyroxenes are completely changed to an assemblage of amphibole and chlorite and the feldspars highly saussuritised. Presence of several en echelon lodes also indicate stratification and segregation by crystallisation differentiation.

8. PROSPECT OF UTILISATION

The Orissa State Government through the aegis of the I.D.C. and IPICOL had explored the feasibility of setting up vanadium production facility at Rairangpur on the Tatanagar-Badampahar broad gauge railway line, about 10 kms. from Kumardubi deposit. Tests on pilot plant scale carried out by ELKEM of Norway under a UNIDO Project on bulk samples of Kumardubi had found the suitability of ore for production of FeV. The proposal envisaged production of 480 tonnes of ferrovanadium (50% V) and 48,000 tonnes extra low phos. pig iron per annum. The annual requirement of ore for the proposed production is estimated to be 90,000 tonnes, thus giving a 20 year life for the project. The ELKEM process involved pre-heating and pre-reduction of ore, flux and non-coking coal in a rotary kiln and subsequent smelting in a submerged arc furnace. While vanadium migrates to molten iron, TiO_2 present finds its way to the slag phase. Vanadium present in the iron is separated in the form of slag containing V_2O_5 by blowing O_2 on the molten metal, as is being practised by Highveld of South Africa. A typical composition of slag expected to be produced from the Orissa ore is as follows:

FeO	19.5 %
V_2O_5	19.8 %
SiO_2	30 %
Al_2O_3	12 %
MnO	5 %
TiO_2	7 %

The vanadium bearing slag is converted to FeV by silico thermic reduction, a process developed by ELKEM.

The other route for recovering vanadium is by chemical process which involves crushing, agglomeration, leaching and precipitation.

In China, ores containing less than 1% V_2O_5 are being successfully smelted for recovery of vanadium. It should be possible to utilise the VM resources of Kumardubi and Betjharan for production of FeV and vanadium pig iron on the basis of technology, which are fairly well proven.

While both Kumardubi and Betjharan could be developed simultaneously, Hatichar deposit with an estimated reserve of about 0.4 million tonnes can provide a reasonable backup.

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Other Minerals

The other minerals and ores which occur in the State and some of which are being mined include pyrophyllite, quartz, quartzite, kyanite, and steatite. Among the potential prospects, platinum group of metals deserve special mention. These are briefly described.

PYROPHYLLITE

Pyrophyllite, a hydrous aluminium silicate, is used mainly in making of refractories. In its other uses such as ceramics and insecticide, pyrophyllite resembles talc. But unlike talc, it is pearly and does not flux when heated. The following specifications have been recommended for its use :

Refractory	Al_2O_3	:	28%	min
	SiO_2	:	60%	max
	Alkalies	: less than	0.5%	
	PCE (Orton)	:	28%	min
Ceramic	Al_2O_3		25%	min
	SiO_2		60%	min
	Fe_2O_3		1%	max
	TiO_2		1%	max
	MgO		0.5%	max
	CaO		0.5%	max
Insecticide	LOI		6%	max
	Matter soluble in HCl		3%	max
	Fe_2O_3		1.5%	max

The origin of pyrophyllite is attributed to metasomatic replacement by hot magmatic solution given off during the hydrothermal phase of granitic intrusion.

Pyrophyllite occurs in the form of quartz-pyrophyllite schist associated with granite and also quartz reef intruding the granite gneiss. The Orissa occurrences are associated with the Singhbhum/Bonai granite. Quartzite is often seen to cap the pyrophyllites.

In India, major deposits are located in M.P and U.P. Rajasthan, Maharastra and Orissa are the other States where workable deposits have been found. A proper assessment of the reserves of pyrophyllite in the country as well as in Orissa is yet to be made.

Pyrophyllite occurrences in Orissa have been recorded in a 90 km long belt extending from Rebna-Palaspal in the south to Remuli-Joda road on the north. The main deposits are at Dhobakuchuda, Balabhadrapur, Anjor, Baliadihi, Madrangajodi, Dalimpur, Nitigotha, Buriadihi, Sidhmath, Sarasposi, Ukchabeda, Roduan, Bolianiposi, Rampakot and Rebna-Palaspal, all in Keonjhar district. Occurrences are also reported near Manada, Joshipur and foothills of Simlipal in Mayurbhanj; near Lahunipada in Sundargarh districts.

Reserves estimated by the Directorate of Mining & Geology on the basis of preliminary investigation are as follows :

Madrangajodi	0.9	million	tonnes
Nitigotha	0.3	"	"
Roduan	0.7	"	"
Rampakot	1.2	"	"

Considering the long belt in which a number of occurrences have been located and the broad surficial dimensions delineated during the course of preliminary investigation undertaken by the DMG, an indicated reserve of 8 million tonnes would appear to be in order.

Four mining leases were subsisting as on 1.4.94. All the leases are in Keonjhar district and working. Production during 1993-94 was 21,000 tonnes, Madrangajodi mine of Sri B. Newatia contributing 20,000 tonnes. Four crushing and pulverising plants have been set up near Keonjhargarh and Joda for processing of r.o.m. pyrophyllite.

The range of chemical composition of pyrophyllite from Madrangajodi, Nitigotha, Roduan are given in the following table

	% Al_2O_3	SiO_2	Fe_2O_3	LOI	Alkalies
Madrangajodi	20-23	69-75	0.2-0.5	2.8-3.9	0.6
Nitigotha	20-23	65-69	0.2-0.5	-	-
Roduan	21-22	68-71	0.2-0.6	3-4	

KYANITE, SILLIMANITE AND ANDALUSITE

Kyanite, andalusite and sillimanite are anhydrous aluminium silicate minerals represented by the chemical composition Al_2O_3 SiO_2. These are mostly used for manufacture of high alumina refractories. These on heating to about 1,350° C are converted to mullite, which remains unchanged on subsequent heating.

The reaction is represented as follows

3 (Al_2O_3 SiO_2) + Heat ----> 3 Al_2O_3. 2SiO_2 + SiO_2
(Kyanite, andalusite, sillimanite) Mullite ----> Free silica

The above property of mullite enables its applications as a high performance refractory for a wide range of industrial applications.

The Expert Group constituted by the Ministry of Steel & Mines has recommended the following specifications for refractory use.

Al_2O_3	54%	(min)
Fe_2O_3	1.5%	(max)
PCE (Orton)	36	(min)

Kyanite group minerals are believed to be products of anhydrous metamorphism of argillaceous sedimentary rocks. In Orissa, occurrence of refractory grade kyanite is confined to Panijia in Mayurbhanj district, where it is being mined intermittently for over 50 years. The deposit has depleted to a stage of exhaustion. The other occurrences are kyanite bearing quartz schist near Magarmuhan, Torodanali, Jhilli, Golagadia, Sikheswar, Kadobasant in Pallahara and Kamakhyanagar sub-divisions of Angul and Dhenkanal districts. The areas feature Archaean meta-sediments represented by quartzite, quartz schist, garnetiferous quartz-mica-kyanite schist, phyllite and amphibolite. Pegmatites and quartz veins occur as intrusives. Kyanite occurring in these locations are low in alumina (less than 45%) and high in iron (more than 2% Fe_2O_3) contents. These can be used only after blending and / or beneficiation.

Production of kyanite in the State is confined to the lease at Panijia in Mayurbhanj district held by Sri K.K. Chourasia. The other lease in Angul district was not working. The annual production of sillimanite comes from IREL's sand separation plant near Chhatrapur, which was of the order of 1,000 tonnes during 1993-94. There is no production of andalusite in the State. The only lease held by Lal Trades & Agencies in Simlipal hill of Mayurbhanj district has not been worked.

SOAPSTONE, STEATITE AND TALC

Soapstone, steatite and talc are three terms used in trade for one and the same mineral, a soft hydrous magnesium silicate with a chemical composition of 3 MgO. 4 SiO_2. H_2O. Soapstone is a term used for a massive form of rock containing the mineral talc in quantities ranging from near theoretical to as little as 50%. Ordinary usage usually restricts the term "soapstone" to impure massive talcose rock, while the high purity massive talc is called "steatite".

These minerals are associated with ultramafic igneous rocks of secondary origin by processes of low grade regional metamorphism.

The minerals have a wider end-use range; in the manufacture of ceramics, as a filler in rubber, plastics; pigment of paints, coating of paper, insecticides, cosmetics, as roofing material and as refractories. In Orissa, the reserves of these minerals have not been assessed. 10 mining leases for this group of minerals were existing in the State, distributed in the districts of Mayurbhanj (4), Sambalpur (2), Sundargarh (2), Ganjam (1) and Dhenkanal (1). Of these, 4 were in operation as on 1.4.94 (2 in Mayurbhanj, one each in Sambalpur and Sundargarh). Production was confined to steatite/ soapstone and ranged from 4,465 to 2,625 tonnes during the last three years with Mayurbhanj district contributing about 95% of the total production.

QUARTZ AND QUARTZITE

The industrial uses of quartz and quartzite are dependent mainly on their silica content and physical characteristics. Quartz is used for manufacture of silicon alloys, and ceramics. Quartzite is used in the manufacture of silica refractories, as a flux in iron and steel and ferroalloy industries and also for manufacture of silicon alloys. Other uses of quartz and quartzite are for manufacture of glass, abrasives and sodium silicate.

The resources of quartz and quartzite are quite extensive. Excepting the coastal plains, quartz and quartzite occurrences are found in almost all the districts of the State in several stratigraphic horizons. Quartz occurs as a constituent of pegmatites and in the nature of veins. Quartzite could be sedimentary (orthoquartzite) or meta-quartzite, recrystallised on account of metamorphism.

The Expert Group has recommended the following specifications for various end-uses of quartz and quartzite

	% SiO_2	Al_2O_3	Fe_2O_3	Physical
Refractory grade	96 (min)	1 (max)	1.5 (max)	Fine grained, granular and compact.
B.F grade	95 (min)	1 (max)	-	Lumpy
Ceramic	97 (min)	2 (max)	1 (max)	
Ferro-silicon*	98 (min)	0.4 (max)	0.2 (max)	

* P & As should be nil

As per the National Mineral Inventory, the recoverable reserve of quartzite in the country as on 1.4.90 are estimated to be 365 million tonnes. Orissa's reserves are placed at 6.7 million tonnes. These figures do not include reserves of quartz and silica sand. As many as 99 mining leases for quartz and quartzite were subsisting as on 1.4.94. Of these, 60 were in operation. The leases were distributed in the districts of Kalahandi (42), Sundargarh (14), Bolangir (7), Mayurbhanj (6), Sambalpur (5), Jharsuguda (9), Keonjhar (4), Boudh (4), Jajpur (3), Koraput (3), Angul (2) and one each in Bargad, Malkangiri and Subarnapur. The State produced 107,000 tonnes of quartz and quartzite during 1993-94. The major producers include FACOR (Bankimunda, Bolangir), MIC Ltd. (Buromal, Bolangir), Sri P.K. Panda (Amjor, Kalahandi), Sm. P. Bhanj Deo (Andhari, Sundargarh), (Jharbeda, Sundargarh), Sri D.C. Das (Kuldiha, Mayurbhanj), Sri R.M. Tripathi (Pandupani, Mayurbhanj), Sri B.C. Sahu (Kanjijharan, Jharsuguda), Sri B.K. Mohanty (Parsala, Keonjhar), Sri D.B. Nayak and Sri P.N. Sahu (Salijanga, Jajpur).

PLATINUM GROUP OF METALS (PGM)

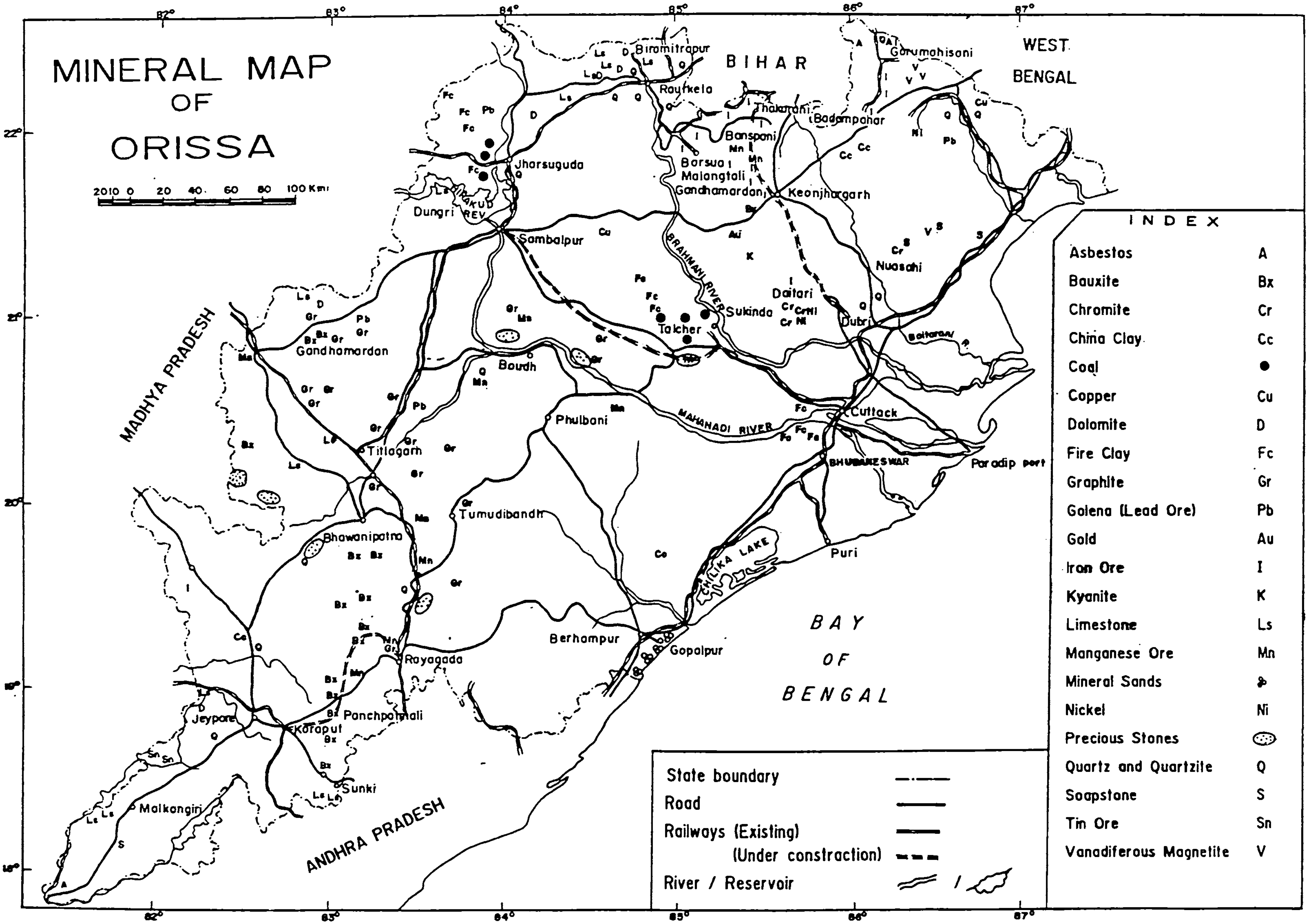
The platinum group comprises six closely related metals : platinum, palladium, rhodium, ruthenium, iridium and osmium, which commonly occur together in nature and are among scarcest of the metallic elements. Their extraordinary catalytic activity, chemical inertness over wide temperature range and high melting points constitute the basis for their use as catalysts in the automotive, chemical and petroleum refining industries and as corrosion - resistant materials in the chemical, electrical, glass and dental-medical industries.

Layered ultramafic - mafic intrusions of Precambrian age are the main source of Platinum Group of Metals (PGM), chromite and Ti-V magnetite deposits as well. About 95% of the world production of PGM come from the lode deposits in South Africa, Canada and undivided USSR.

Regional exploration by the GSI has revealed significant values of Pt + Pd in Sukinda and Boula-Nuasahi chromite fields of the State. In Boula-Nuasahi area, a magmatic breccia zone close to basic - ultrabasic contact has indicated Pt + Pd values as high as 2-3 ppm in some sections. In Sukinda ultramafic field, the chromite bands have recorded upto 400 ppb of Pt and 500 ppb of Pd. Limonitic rocks capping the ultramafic rocks have indicated Pt + Pd from 40 to 290 ppb.

In view of the encouraging results, GSI has decided to take up exploratory drilling and systematic sampling in the potential blocks.

[The compilation is based on contributions by Dr. J.N. Das, Deputy Director of Geology and Shri. B.D. Rath, Joint Director of Geology of the Directorate of Mining & Geology, Orissa and agenda papers of the meetings of the State Geological Programming Board.]



MINERAL MAP OF ORISSA